Transformable and transportable architecture: analysis of buildings components and strategies for project design.
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Final Master Thesis
Architect Carolina De Marco Werner

Professor PhD Architect Ramon Sastre Sastre

Universidad Politécnica de Cataluña
Escuela Técnica Superior de Arquitectura de Barcelona
Abstract.

The present Master Thesis is a research about different aspects of transformable transportable buildings, like components as mechanisms for movement, building design strategies and construction detailing, aimed a better understanding of the design and technical necessities of this particular type of architecture.

The first application for transformable and transportable buildings were developed during post-war period in an urge for solving housing problems and the transformation of the industries, highly influenced by the development of spatial structures. And until few years ago, the design of this type of buildings was only focused on temporary structures or few applications to real building solutions being pure concepts of futuristic image but with the lack of technical development.

Recently, a new type of transportable and transformable architecture is being produced as solutions for every-day-live use, and accepted in the community they are inserted. In this type of projects the investigation is going to be focused, analyzing from building components and connections to technical design.

Keywords: Transformable, transportable, kinetic connection, movement mechanisms, dynamic structures, deployable, mobile architecture.

Abstracto.

La presente Tesis de Máster es una investigación que trata sobre diferentes aspectos de edificios transformables y transportables, tales como componentes como mecanismos para generar movimiento, estrategias de diseño y detalles constructivos, enfocada en mejorar la comprensión de las necesidad técnico-constructivas de este tipo particular de arquitectura.

Las primeras aplicaciones de edificios transformables y transportables fueron desarrolladas durante el período de posguerra como resultado de la necesidad de solucionar problemas habitacionales y la transformación de las industrias, altamente influenciados por los avances de las estructuras espaciales. Y hasta pocos años, el diseño de este tipo de edificios era sólo enfocado en estructuras temporales o pocas aplicaciones a soluciones reales, siendo la mayoría puros conceptos con una imagen futurística pero con deficiencias en su desarrollo técnico.

Recientemente, un nuevo tipo de arquitectura transportable y transformable está siendo producida, como soluciones para el uso diario y aceptado por las comunidades donde son insertados. En este tipo de proyectos se concentrará la investigación, analizando desde los componentes y conexiones de los edificios hacia los aspectos técnicos del diseño.

Palabras Clave: Transformable, transportable, conexiones móviles, mecanismos de movimiento, estructuras dinámicas, desplegable, arquitectura móvil.
The city of Sophoria is made up in two half-cities. In one there is the great roller coaster with steep humps, the carousel with its chain spokes, the Ferris wheel of spinning cages, the death-ride with crouching motorcyclists, the big top with the clump of trapezes hanging in the middle. The other half-city is of stone and marble and cement, with the bank, the factories, the palaces, the slaughterhouse, the school, and all the rest. One of the half-cities is permanent, the other is temporary, and when the period of its sojourn is over, they uproot it, dismantle it, and take it off, transplanting it to the vacant lots of another half-city.

And so every year the day comes when the workmen remove the marbles pediments, lower the stone walls, the cement pylons, take down the Ministry, the monument, the docks, the petroleum refinery, the hospital, load then on trailers, to follow from stand to stand their annual itinerary. Here remains half-Sophronia of the shooting-galleries and the carousels, the shout suspended from the cart of the headlong roller coaster, and it begins to count the months, the days it must wait before the caravan returns and a complete life can begin again.

Italo Calvino
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1. Introduction

When making the introduction on portable architecture Kronenburg (1999) said that “... easily movable buildings were amongst the earliest artifacts made by human beings and some of these traditional architectural patterns have not only existed more or less unchanged for millennia but are the inspiration from which the permanent building forms of today have arisen” and that “In a society that is making more stringent demands on the physical environment and where the surrounding economic, social and cultures climate is in a state of constant and dramatic flux, a form of architecture that can respond to change and that is sensitive to widely differing needs is required”. These citations are directed to transformable architecture, and not only Kronenburg, but most authors have begun describing their works and expectations towards this typology as if the adaptable structures have the potential to solve difficult problems in a “dramatic changing world”. This seems strange, since transformable and transportable building are and have been negligible by the architecture community, and seen as a low-quality tool, cheap and disposable by the general public. The debate of contrast is what motivates initially this study.

On two moments there has been noticeable interest of the professionals of the area in this field of study. The first, on the second-half of last century - the post war period- the architects in association with government institutions where trying to develop urgent solutions to the lack of housing of the moment (Figure 1). With the support of the industries, that where in recession since the end of war, there was a mass production of prefabricated buildings and the mobile industry expanded with the need for affordable rapidly constructed housing (Smith, 2010). The princi-
Pal influence was by the Dymaxion House—projected in 1927 and improved thought the years, by Buckminster Fuller (Figure 2). A prototype of a habitable machine: based on aircraft technologies were designed to incorporate mobility, to be prefabricated and have a low cost production (Echavarria, 2008). The architecture developed in this moment was believed to be the future of buildings constructions, it was known by the futuristic characteristics of its design and the aggregation of other industrial technologies that weren’t normally associated with architecture, like the automobile industry. It was also the time of high-tech movement, an era of big architectural ideas with publications of manifestos of highly industrialized wonders from architects such as Archigram and Hopkings.

During the next decades this architecture had applications mainly in algorithmic geodesics, the scissors structures and in tensile buildings, and since the turn of the century is detectable a new re awake. The second moment has the direct influence of Buckminster Fuller— with his work in spatial structures, Frei Otto— with his work in cable-net structures, and their colleagues, is perceptible as the new generations architects are developing researches on technologies for scissors and pantographic structures (Figure 3). Also known as kinetic, this architecture have extensive types and possibilities of structures and techniques, and the need of high precision on design and construction favors the need of a high develop technique.

The claim in both moments is the same: a fast and precise architecture that can adapt itself; an industrialized and sustainable architecture that can help to adapt to a changing environment and to a society that, now globalize, is once again in constant movement. However, when talking specifically about transformable portable architecture, and taking account on: if the specialized publication’s claims, with fair arguments, that it’s a good architecture that can make a difference; if the studies researches demonstrate that its buildings are not only viable, but highly technological and have a better performance and environ-
mental benefits than traditional buildings- it’s possible to question where is this architecture being designed and constructed. And with a fast research on actual projects the question can be change to why these buildings are not being constructed, or so poorly constructed.

Some preview assumptions can be done about the actual professional work on this area. The research are mostly done in scissors and tensile structures with large attention on its technical characteristics as a unit, but a few applications to a real building design or construction are applied, and hardly any research comes out to a prototype phase. Transformable structures are often associated with shelter after disaster situations, and the most projects come as donor-led temporary portable shelter to a recent catastrophe that hit the news worldwide. These designs usually are pure concepts, poor technical development and hardly executable, but they have the high technological and futuristic style, with quality pictures and presentations that can make into any architectural publication (Figure 4 and 5). And they in fact do, when searching in publications for transformable and transportable design prevail the shelters for a world, which apparently, is in collapse.

In recent years, due to urgent need for multi-functional buildings and also the necessity to maintain and respect the environment in front of building’s wastes, the demands for transformable and changeable structures has increased rapidly (Asefi, 2011). But the society in general still prefers stable and reliable, and has a tendency to look for luxury and comfort (Oostra, 1998). So it’s understandable the preference for the traditional construction, and portable are often saw as passion of the moment making it harder to the projects pass the prototype phase.

However, feasible flexible architecture can be found in all areas of human activity: commerce, industry, education, medicine, military and entertainment (Kronenberg, 2007), and digging deeper into projects is possible to identify an active class of buildings developed and constructed in the last decade. They aren’t the shelter for disaster situations, but buildings with every-day-live use purpose that are active in the community they are inserted. These projects are not trying to adapt to a future changing environment – which they could easily do- but responding to actual social needs. They challenge our preconceptions of what buildings can be, speculating what architecture can do. Being designed by offices and architects with few or none connections with research centers, these buildings are the result of individual design inquires, executed with the local materials and technologies, and no design guidelines. Dina E. El-Zanfaly says that there have been some precedents on how to design kinetic architectural structures, but they all just present the types 4- Monohedron deployment process. High concept, not technical definitions.
5- Monohedron once in open position, project by Andrej Cverha.
of motions and elements used in these structures, there aren’t any guidelines or frameworks to help the professional to design. And even the classifications are something complex, since there are many terms to describe in this kind of architecture - kinetic architecture corresponds to a large field of study and can make references to many subjects.

In this research the intent is to clarify design principles and mechanisms, and help professionals on the specification process. The first part of this work is a definition of transformable and transportable architecture and it classification. The second part is to explore the possibility of movements and present some solutions for their constructions. The third, and principle part is to present and analyze projects that have been build, reviewing their deficiencies and achievements when resolving technical difficulties.

1.1.Objectify

1.1.1.Assumptions

Portable buildings open a vast area of actuation that is not possible with traditional architecture. The implemented constructions techniques and easily transformations give then the advance of been located where conventional buildings can't be and promote uses, that are not only unlike to stationary architecture, but complementary and much times the same. Transformable buildings, with its movable components and mechanisms, have the potential to enlarge the area of portable packages and have larger adaptation possibilities. Having both combined, it’s possible to work with the concept that, rather than refurbishing and expanding an existing construction, a parallel and independent building can be contracted and temporary located on the site to fulfill the users need. There by, materials, time and efforts would be saved.

The transformable and transportable architecture have the potential to serve users beyond the temporal-transitory uses – but should never discard them. As a society in movement and which a large urban growth, many times unregulated, professionals and society should work with the vision that temporary in sitting does not necessarily mean temporary in existence and it is their ability to move that make such buildings reusable and recyclable (Kronenburg, 1998). As well, introduction of good industrialized techniques combine with improving design can provide quality buildings, potentially as reliable as the traditional and stationary.

1.1.2.Limitations

Unfortunately, temporary buildings are mostly on the
margins of society, seen as disposable and cheap and with poor, or no design concept. Every city at some point has the container style buildings as temporary school, hospital, office or as supporting at the construction site. They are also associated with ephemeral interventions, where the structures usually have only purpose to impact and call attention to its promoters (commercial publicity, artist or architects associations).

It has also been observed that there is little guidance about the subject, this have been observed also by others students of the area, as Joshua David Lee on his thesis about terminologies definition, he says “My initial impression was that there just wasn’t much written about this type of architecture and my understanding of the genre was limited to serendipitous discovery of texts and case studies. By digging deeper into the literature I expected to find a wealth of lessons learned from the field. Instead, I found that the subject of change in architecture was not only linguistically disjointed, but offered very little critical reflection on what had been proposed and built”.

The movement’s components are poorly explored since its design concepts are unknown to most professionals, and, for a transformable building to work properly, the conjunct of movement mechanisms, joints and structure stability have to work together assuming very low rates of error. Not having this knowledge, most architects prefer ignore the potential of this kind of architecture rather than get involve with the research need to improve the design development. And those projects that are developed usually are conceptual designs that hardly get into prototype phase, since their project design don’t contemplate the technical specifications needed to be constructed.

The nomenclature used when talking about transformable architecture is confusing, coincidental and each author uses its own denomination when classifying types and sub-types of motion structures.

Buildings are durable goods. This means that clients, especially project developers who professionally sell or lease buildings, are afraid to use new and unspecified products. As said, in 2001, by Douglas Heingartner “People buy into the possibility of freedom that mobile living implies, but at the end of the day they’re just as happy to cocoon themselves in brick-and-mortar houses that ooze history out of every cornice”.

1.1.3.Delimitations

This work, although some bibliographic references are from 60s and 70s, aims to present the vision of actual contemporary transformable architecture. Therefore, the works here presented and analyzed -with few exceptions- from the year 2000 to now days. The bibliography has been researched in English,
Spanish and Portuguese, and the projects have been investigated in German as well.

To be able to explore and analyze technical and constructive details, the second delimitation is that the projects to be selected for this study should be built in commercial or at least in prototype form. Therefore the conceptual projects have been excluded, except the ones that have been developed inside a research institute.

Also, the analysis is concentrated in transformable transportable buildings, so the third condition is that the buildings should be portable— as itself or with transport vehicles assistance, and deployable – to reach its final form with moveable components, and the process should be reversible.

In addition, to show that this architecture can be inserted in day-to-day live, there have been a special consideration for projects that have social relevance and their use is active on a day bases scenario. Just as Zuk said in 1970, “Even the very basic question of whether man can do something has changed to whether he should. It is recognized that it is no longer the task of the architect to provide only shelter”.

1.1.4. Significance of the study

With the aim of a better understanding of the design and technical necessities of transportable and transformable architecture, this research works with the importance of technical knowledge on elaborating a professional project. It can also help to develop a better product, since there are few books on the subject, the research is based on prefabricate architecture and whenever possible adapted. Change cannot be impose on users and professionals, but, if the final building has a high quality and attractive design, the recognition of this architecture can be improved from cheap and disposable to what it should be seen as – good architecture based on the principles of efficiency in form, light weight in materials, flexibility in purpose (Kronenburg, 2005).

This study is a base for a research in progress that will be completed in future works.

1.2. Methodology

The methodology of this work is based on review research and projects under the “transformable architecture” and variants. To reach the objectives propose the methodology were divided in 4 moments:

1- Definition and nomenclature of transformable architecture:
and analysis of past publications will be done and a new and personal nomenclature and classification will be defined to be used in this work.

2- Design Criteria: A research and analysis will be done in order to define the principles of movement's mechanisms and components. If possible, technical specifications will be related with each movement mechanism.

3- Projects Classification: projects will be search on on-line and written publications under the delimitations boundaries, than classified based on design criteria's.

4- Projects Analysis: An analytic analysis will be done, trying to define the achievements and failures of the projects and in this way, help the future professionals.

The first and second are research based on the publications that have been found about the theme. It's an analysis of what others authors have written about the theme with a personal and critical point of view.
2. Transformable Architecture: Definition, Nomenclature and Classification

Transformable, kinetic, deployable, adaptable, there is an extended vocabulary to refer to a building with movable parts and/or components associated with a shape change. While specialized terms are diffuse, the general use of nomenclatures is confusing. It’s normal that the same term is associated with different definitions, and the same happens with meanings that are associated with distinct names. Publishers don’t clarify if the nomenclature and classifications used are associated with typology types, structures or mechanisms. It’s very usual that each professional redefines the terms accordingly with its own needs.

The reality is that the literature reviews on this subject are either manifestos or contributions to the culture industry. One valuate the hypotheses, the other generate advertising revenues for design – both lack the critical reflection needed (Lee, 2012). And the resembling classification criteria used can make difficult to segregate the individual differences between the terms, this affect directly the design and new research of transformable architecture.

This chapter is an attempt to clarify the definition of transformable architecture and review the nomenclature and classifications that have been used by the past authors. According to characteristics to be defined, a new classification is going to be suggested and used in the rest of the study. The analysis here realized is based on referred authors and presents a single person point of view. It maintains open the debate and gives the possibility to evaluate the definitions and classifications in future works.

2.1. Definition of Transformable Architecture

In 1970, in one of the first books that classified and described movement in architecture, Zuk and Clark state that “nothing is permanent”, the design is a continuous process that will persist after the building is erected. They characterize the kinetic as “the architectural form could be inherently being displaceable, deformable, expandable or capable of kinetic movement” (Zuk and Clark, 1970).

In 2003, Robert Kronenburg states that, under a transportable point of view, kinetic is “building or buildings compo-
ments with variable mobility, location and/or geometry” (Kronenburg, 2003). The same author, in 2007, says that transformable “includes changing design buildings, space, form and shape by physically altering its structure, interior or skin. It is an architecture that opens, closes, expands and contracts”. And portable “includes buildings that move from one place to another in order to better play its role: it is an architecture that rolls, floats or flies” (Kronenburg, 2007).

This research aims to evaluate the technical means of a building transformation and design decisions required for it success. In order to better explain transformation from this technical perspective, it’s important to quote Lowell Normann, who describes his own transformable structure as “a portable structure that, without disassembly or separation of it basic parts, can be rapidly transformed between its fully erected configuration and its fully collapsed configuration by one individual unaided by other person” (Norman, 1989) (Figure 1). And also quote Maziar Asefi, who publish in 2010 his research where he “describes a distinct class of structures consisting of rigid, or transformable elements, connected by moveable joints that can change their geometry reversibly and repeatedly and have the innate characteristic of controlled reconfiguration” (Asefi, 2010) (Figure 2).

The transformations, in the buildings that are going to be evaluated, are a requirement to have a full use of the architectural possibilities. The start force that generates the movement can be natural (human handed) or mechanical (construction automation). There are numerous examples of stressing, folding, creasing, hinging, rolling, sliding, nesting, inflating and fanning mechanisms that provide a rich source of strategies to be used in transformations.

1- Examples of transformable structures where the movement changes the form and the use of the building.
2- 3x1 expandable container unit. In this case all the movable elements are continuos connected.
2.2. Nomenclature and Classification

Nomenclature

The necessity to clarify the terms used to refer to buildings with some kind of moveable elements is clear and have been recognized by several authors, some which realized extended studies related to nomenclature, definition and typologies of uses. It’s the case of J.D. Lee, who in his research determine the use of four terms (adaptable, kinetic, responsive and transformable) through the publish literature and reaches the following conclusions (Lee, 2012):

Adaptable architecture: buildings planned to be easily altered or modified to fit changing social functions before and after occupancy (Figure 3). Adaptable projects are generally residential, socially motivated, and often accomplished through movable wall systems.

![Figure 3](image)

Kinetic architecture: structures or components with perceived or actual variable mobility, location, and/or geometry (Figure 4). Because the term kinetic is closely associated with aesthetic/metaphorical rationales these projects (installations, retail, and performance spaces) generally seek an aesthetic effect or simply try to capture attention.

![Figure 4](image)

Responsive architecture: buildings or social process of the built environment that answer to the social and/or environmental stimulation of a specific place during the design phase of a project (Figure 5). Responsive projects include many building types but also include works of urban planning and landscape architecture.

![Figure 5](image)

3- Adaptable architecture, the building can change through the different occupants in its lifetime.
4- Kinetic architecture, the capacity of the building to be mobile.
5- Responsive architecture.
Transformable architecture: structures that are able to rapidly take on new shapes, forms, functions, or character in a controlled manner through changes in structure, skin and/or internal surfaces connected by articulated joints (Figure 6). Transformable projects are generally structural applications less focused on aesthetic effect than on improving the functional requirements of the project (i.e. keeping the rain out or letting the sun in) and are often open-air projects such as retractable roof stadiums and pavilions.

The principal conflict is between the transformable and deployable definitions, which are often defined as the same. Referring to deployable, two citations become important, the first is from Alan Brookes, who categorize that in portable architecture all systems can be categorized under either “deployable” or “prefabricated” structures and states that “deployment concerns not the pre-manufacture of elements but more or less pre-assembly of the entire structure in a factor and the unfurling or deploying of the structure on site. As such the building form tends towards a finite element as a complete form or a series of add-on elements” (Alan Brookes, 1999). The second is from Maziar Asefi that evokes that sometimes deployable and transformable are the same, whereas “Deployable structures are structures capable of large configuration changes in an autonomous way. Most common is that the configuration changes from a packaged, compact state to a deployed, large state. Usually, these structures are used for easy storage and transportation. When required, they are deployed into their service configuration. Some incorporate their transportation method into their permanent structure and may be built on a chassis or a hull. Deployable structures are sometimes known under other names like transportable, expandable, extendible, portable, developable structures.”

In an easy way, it’s possible to make references with everyday objects. Deployable as the umbrella (Figure 7), where all the pieces are connected and need to move together in order to function correctly. Transformable is a chair, that which the rotation and sliding of some parts can turn into a table - all the pieces are joint together, but they don’t need necessarily move together, it would be more like a pre-order of unfolding elements. Architecturally, is viable to say that deployable are more related to development of pantographic and tensegrity structures and transformable to pods, packed and pneumatics. But as said by Zuk and Clark “the typologies may overlap and an example can fall into more than one category” (Zuk and Clark, 1970). Deploy-
able is the act of movement on a structure that can be classified as transformable (Figure 8), but not all transformable architecture can be defined as deployable.

For an additional knowledge, with the use of Cambridge Dictionary, a list of common-use words in the transformable architecture descriptions where explored and classified accordingly to its definitions (Table 1).

<table>
<thead>
<tr>
<th>Comparative chart between terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>To arrange / to change</td>
</tr>
</tbody>
</table>

**Classifications**

Over the years many researchers have developed classifications for transformable architecture. Indifferent if the nomenclature was transformable, kinetic or deployable, the classifications methods are based on the perspective and field of study of each author (Table 2). The categorizing can be from a structural and mechanical observation, or an evaluation of applications and mechanisms considering the transformations extremes (fully folded or fully deployed state). The most important consideration to be made is that a single building not necessarily belong to a single class, it characteristics and systems can be diverse and take place on more than one sub-category.
<table>
<thead>
<tr>
<th>Researches</th>
<th>Classification Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zuk and Clark</strong></td>
<td>1. kinetic controlled static structures</td>
</tr>
<tr>
<td>Kinetic architecture through archi-</td>
<td>2. dynamically self-erecting structures</td>
</tr>
<tr>
<td>tectural applications and structural aspects</td>
<td>3. kinetic components</td>
</tr>
<tr>
<td></td>
<td>4. reversible architecture</td>
</tr>
<tr>
<td></td>
<td>5. incremental architecture</td>
</tr>
<tr>
<td></td>
<td>6. deformable architecture</td>
</tr>
<tr>
<td></td>
<td>7. mobile architecture</td>
</tr>
<tr>
<td></td>
<td>8. disposable architecture</td>
</tr>
<tr>
<td><strong>R.H. Kronenburg</strong></td>
<td>1. Fully portable and transportable buildings which are manufactured whole.</td>
</tr>
<tr>
<td>Kinetic structure</td>
<td>2. Relocateable and transportable buildings which are assembled on site using transportable parts.</td>
</tr>
<tr>
<td></td>
<td>3. Discontinuous buildings which are fully disassembled in a number of components for transportation.</td>
</tr>
<tr>
<td><strong>Alan Brookes</strong></td>
<td>1. Flat Packed</td>
</tr>
<tr>
<td>Structure type of portable archite-</td>
<td>2. Pantograph</td>
</tr>
<tr>
<td>cture with a prefabrication perspec-</td>
<td>3. Membrane Systems</td>
</tr>
<tr>
<td>tive</td>
<td>4. Pneumatics</td>
</tr>
<tr>
<td></td>
<td>5. Tensegrity Structures</td>
</tr>
<tr>
<td></td>
<td>6. Pods or Capsules</td>
</tr>
<tr>
<td><strong>Maziar Asefi</strong></td>
<td>1. Transformable tensile structures</td>
</tr>
<tr>
<td>Structural types of transformable ar-</td>
<td>1.1. transformable tensile membrane</td>
</tr>
<tr>
<td>chitecture</td>
<td>- transformable fabric structures</td>
</tr>
<tr>
<td></td>
<td>- pneumatic structures</td>
</tr>
<tr>
<td></td>
<td>1.2. transformable compressive-tensile</td>
</tr>
<tr>
<td></td>
<td>- tensegrity</td>
</tr>
<tr>
<td></td>
<td>- non-tensegrity strut-cable</td>
</tr>
<tr>
<td></td>
<td>2. Transformable bending and compression structures</td>
</tr>
<tr>
<td></td>
<td>2.1. spatial bar structures</td>
</tr>
<tr>
<td></td>
<td>- pantographic with straight bars</td>
</tr>
<tr>
<td></td>
<td>- pantographic with angulated bars</td>
</tr>
<tr>
<td></td>
<td>- reciprocal structures</td>
</tr>
<tr>
<td></td>
<td>2.2. spatial frame structures</td>
</tr>
<tr>
<td><strong>Felix Escrig</strong></td>
<td>1. Tensile folding structures</td>
</tr>
<tr>
<td>Types of transformable structures</td>
<td>2. Tensegrity roof</td>
</tr>
<tr>
<td></td>
<td>3. Retractable roof</td>
</tr>
<tr>
<td></td>
<td>4. Umbrella structures</td>
</tr>
<tr>
<td></td>
<td>5. Mobile structures</td>
</tr>
<tr>
<td></td>
<td>6. Deployable Structures</td>
</tr>
<tr>
<td></td>
<td>7. Lifted Structures</td>
</tr>
</tbody>
</table>

**Table 2** Comparative chart of existing classification groups with focus of research studies.
2.3. System Classification

Transformable and transportable buildings are the target of the research, which the objective of evaluation the interaction of mechanical, structural and materials as a full system and the design strategies to develop this system. Prefabrication is the key to a higher specified construction and therefore the categories used by the architect Alan Brookes studies are going to be base for the creation of the system classification.

Flat packed

Pre-hinged construction systems, are usually complemented with a kit form of auxiliary parts (Figure 9). Folding mechanism is commonly used in this system.

Pantograph

Sophisticated hinged systems usually use means of scissors mechanisms as a deployable structure (Figure 10). This is a large and complex field in architecture with several research groups and publications regarding it. This thesis does not aim to cover this subject peculiarities, it presume a basic preview knowledge that permits to evaluate how pantograph interact with other systems.

Membrane systems

A combination of pre-stress membrane with structure (movable or stationary) that can change its geometry or shape in a deployment movement by modifying the apply tension (Figure 11).

Pneumatics

Membrane inflate or air-supported buildings (Figure 12).
Tensegrity
Structure composed by cables and bars in a pure tension and pure compression mode, with permits the transformation process. It gives the possibility of a high degree of transformability, but there is still no built example of transformable tensegrity structure (Asefi, 2010), so there won’t be further exploration on the subject in this study.

Pods or capsules
Pods are essentially skin supports used as transportation and static structure (Figure 13). Commonly in a container volume and shape, it’s the most used in the construction field. Besides the basic movement elements—rotation and translation, it is used as a hybrid, where it integrates the exterior skin with another of the transformable system.

Taking in consideration that the work of Zuk and Clark provide an important compilation of information, but more than a group by types, it can be considered a group by characteristics of buildings and buildings components, it’s going to be used as complement as characteristics of the system classification.

Kinetic controlled static structures: Based on the fact that "all structures do move" due to conditions of load, wind and vibrations, this is a resource used to implement structural system and auxiliary in stability. Usually used in large-scale structures, it’s not going to be further explored in this research.

Dynamically self-erecting structures: by the joints and connections systems in the structure, these are buildings that can be erected without an auxiliary support. Usually it means that the structure is stable at all times, even during transformation.

Kinetic components: the small-scale move components that realize the basic principles of movements – rotation and translation.

Reversible architecture: the ability to a building to be dismantled in a non-destructible or collapse in a manner reverse to that which it was erected.

Figure 12

Figure 13

12- Pneumatics
13- Pod and Capsules
Incremental architecture: involves addition, subtraction and substitution in order to meet ranges of configurations of components or interaction with other modules.

Deformable architecture: the change that affects the whole form limited by an initial envelope, all parts are connected and continuous. Deformable architecture refers, now days, to the alteration of form in single elements, as a reaction of external forces actions and the material. For this research the term that is going to be used is expandable architecture.

Mobile architecture: the building moves as a total unit.

Disposable architecture: the possibility to the building to be substitute by a new one that respond better to the use needs. It’s possible to look at it as the recyle of components and material that take place in prefabricated and sustainable architecture.
3. Transformable Buildings Components

It’s recognizable that even a well-conceived prefab system of assembly is not fully understood in all of its parameters until it is made physical (Smith, 2010). And sometimes designing complex systems with movable joints, even with advanced knowledge and the auxiliary of software and models, can be difficult to comprehend it as a whole and this generate problems that cannot be foreseen.

To a better understanding of how transformable buildings work as a whole (Figure 1), a division of its components has been made. It takes into consideration that a mobile system can be divided in three parts: structural (rigidity, stability, balance and endurance), functional (transformability and transportability) and technical (modulation of elements, lightness of system and assemblage between elements). And that the most common malfunctions in transformations are the operation of movable mechanisms, the functioning of joints and sealing joints and the finishes between movable panels or components in the relation of interior/exterior.

Therefore, the transformable buildings components are divided into movement mechanisms, load bearing structure and planar surface components. In terms of design and function, the three have to be take into consideration synchronized (Figure 2), because one interferes direct into another and if the three are not well coordinate and specified, the system won’t work properly and the malfunctions will appear.

3.1. Movement Mechanisms

Analyzing the practical, functional and stability criteria and designing a movable joint, for a kinetic connection, is an extensive and technical work, which usually marks a lack of classified information and knowledge of the area by most architects. Industry catalogues have been providing mostly documentation about mechanisms connections of transformable buildings.

The elements provided by this industry have a vast extension of options - but at some point limited by the standards of the industrialization process. And the best advantages provided by a commercial product are the technical documentation and specifications (Figure 3), which usually have the required cer-

1- Nebula by Maynard Architects. Relation of the connection between the container and the movable walls.
2- Project design process. It’s necessary to constantly update all components once one is modified.
3- Exemplar of a hinge from a catalogue with it technical specifications.
ifications for its performances; these documents have a large benefit on projecting phase and with buildings authorities’ approval. Different from custom-made or new developed system (Figure 4), that needs to go through all planning and approving process to meet the technical requirements, which can be long and complex.

Nevertheless, indifferent if the project is using standard or custom-made products, the professionals must have previous knowledge of connection elements and their relation with type of movement desired to make the correct choice. And is this lack of knowledge that difficult the design process and provided most of the constructions malfunctions. So, for further understanding and design support, an analysis of types and uses of mobile connections will be developed.

3.1.1. Movement Principles

Based on axis of movements and degrees of freedom, three basic movements can be identified: rotation, translation and rotation and translation. The first, rotation (Figure 5), is realized when an object change orientation by rotating in the coordinate axes; the second, translation (Figure 6), is a linear movement realized parallel to the coordinate axes; the third is the combination of both. Axes of movement have three degrees of freedom (x, y, z) and the combination of movements means that a connection can have one to six degrees of freedom, meaning one as a simple rotation hinge and six a spatial revolution joint. Many connections mechanisms have constraints to restring the degrees of freedom and control the movement realized.

![Figure 4](image4.jpg)
![Figure 5](image5.jpg)
![Figure 6](image6.jpg)
![Figure 7](image7.jpg)

4- Some examples of the possibility of custom-made connections.
5- Tree degrees of freedom for rotation.
6- Tree degrees of freedom for translation.
7- Table of movements in rigid buildings elements.
Mechanical movement in rigid elements (Figure 7) can be limited to the previous three: rotation, translation and rotation and translation. These movements in general are performed by basic mechanisms which only one degree of freedom, a hinge for rotation and a rail for sliding. The combination of them permits a variety of movements in connections with change of axis, strength and direction that are going to be analyzed further in this chapter.

The gravity has a direct effect on how movements are realized, and weight, size and type of material used are relevant for the type of movement. Deformable building elements (Figure 8) also are able to realize the basic movements, but the combination of flexible materials that permit some change of shape allow other movements to take place based on the material properties and dimension of elements.

<table>
<thead>
<tr>
<th>Construction system</th>
<th>Type of movement</th>
<th>Direction of movement</th>
<th>Parallel</th>
<th>Central</th>
<th>Circular</th>
<th>Peripheric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membranes, static load bearing structure</td>
<td>Gather</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roll</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Membranes, movable load bearing structure</td>
<td>Slide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rotate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rigid constructions</td>
<td>Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rotate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8- Table of movements in deformable building elements.
9- Project Küchenmonument of Raumlab, the expand movement of a deformable membrane.
10- Expandable shelter system of Gichner Systems Group, Inc. with the rotate an translate movement for the open of building.
11- Comparative chart between type of movement and construction system based on Friedmann Kugel draws.
Friedemann Kugel, in 1979, made an analyses, mainly in roofs, of types and directions of movement related with construction systems using a matrix chart (Rebello and Bogea, 2005) (Figure 11). This diagram helps to illustrate the possibilities of movement accordingly with the materials and systems used.

The mechanisms joints can be divided into lower pair and higher pair. Zong and Yan explain that “a lower pair is the one in which contact between two rigid members occurs at every point of one or more surface segments. A higher pair is one in which contact occurs only in isolated point along line segments.” The lower pairs are classified in six different types (Figure X), and the connection between then is known as linkage (Figure X). In contrast with the simplicity of motions from lower pair, the higher pair has infinite number of possible geometries (Figure X), and whenever there is one higher pair or more, the connections are known as mechanisms.

<table>
<thead>
<tr>
<th>Joint name</th>
<th>Letter</th>
<th>Number of degrees of freedom</th>
<th>Typical form</th>
<th>Sketch symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revolute joint (hinge, turning pair or pin)</td>
<td>R</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prismatic joint (slider or sliding joint)</td>
<td>P</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screw joint (helical joint or helical pair)</td>
<td>H</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylindrical joint (cylindrical pair)</td>
<td>C</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spherical joint (ball joint or spherical pair)</td>
<td>S</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planar joint (planar pair)</td>
<td>P</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some of the higher pair joints

<table>
<thead>
<tr>
<th>Joint names</th>
<th>Number of degrees of freedom</th>
<th>Typical form</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical roller</td>
<td>1</td>
<td></td>
<td>Roller rotates about the instantaneous contact line and does not slip on the surface.</td>
</tr>
<tr>
<td>Spatial point contact</td>
<td>5</td>
<td></td>
<td>Body can rotate about any axis through the contact point and slide in any direction in the tangent plane.</td>
</tr>
</tbody>
</table>

12- Multi bar linkage.
13- Table of lower pair joints.
14- Table of higher pair joints.
3.1.2. Movable Connections

On a transformable building, in order to permit the movement to occur, static elements are connected by movable joints, converting them into kinetic components. And, although many constructions absorb the static load bearing structure in their transportable container, these kinetic independent components that form the building must be mandatory load bearing of, at least, its own weight and gravity (Figure 15). Taking this into account, is possible to understand that kinetic joints are not only a connection between two elements, it must also transfer loads while permit relative motion in some directions while constrain in others. The types and direction of motion are related with the degrees of freedoms permitted by each joint, they derivate from the combination of the axis of the movement and the typology of movement.

The first thing to observe when choosing a connection is if it is self-load bearing or if it makes part of the whole structure. Many movable structures once completed its transformation, constraint the connections and become a static structure, in a reversible process. There comes the importance of the adequate distribution of loads also when the element is stationary. Both hinged and bearing have a extend options in commercial catalogues and it’s easy to find the load specification on the technical documentations.

Revolution Joints

Revolution joints are the typical connections of hinged elements that turn around an axis. They are classified as lower pair and usually only have a single degree of freedom of rotation with the purpose of swiveling the elements connected. Some examples are hinges, flaps and turning pair which are used to open and closing entirely the components that they connected.

The custom made products are always an option for special specifications against industry standardizations, but discouraged by the amount of cost and time it consumes to make it thought regulations. Commercially there is an immense variety of hinges (Figure 17) that only exploring the industry catalogs one can have an idea of the available options.

For developing specifications, some basic knowledge is needed. Besides if the hinge fits the overall design, it’s important

15- Nebula by Maynard architects, the container absorbs the static structure, but the panels connections must be load bearing of its own weight.
16- Illustration of hinge operation and force actuation.
17- Example of commercial revolution joints.
to know the axis of rotation, the load that the hinge must stand and its relation with size and material and the angle of movement. These first specifications (Figure 16) are probably the most important; the load can determine the number and size of joints needed, and the axis the necessity of angle and torque control- that can be made with detention and friction hinges (Figure 18) or by a supporting pneumatic actuator. Also, to assist in the specification of the torque, is possible to find in on-line programs that help calculating the torque required by a hinge in relation of the size and weight and angle of the component to be supported. Easy to use, these programs are usually provided by the connections companies themselves (www.reell.com and www.en.vinksda.nl).

Other considerations needed is the cycle of use- is the movement frequent or an isolate action; the space needed to the hinge be installed and the gap between connected elements that it generates- for sealing joinery see surface components; the regulations that the project may have to meet and how it affects the connections choices- security, construction, sanitation, etc. In general, the hinges are already certified to meet the indus-

Figure 19

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Specification</th>
<th>Torque (inch-lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYM-1522-05</td>
<td>4150</td>
<td>0.15</td>
</tr>
<tr>
<td>SYM-1525-05</td>
<td>5150</td>
<td>0.25</td>
</tr>
<tr>
<td>ASY-1522-05</td>
<td>4150</td>
<td>0.15</td>
</tr>
<tr>
<td>ASY-1525-05</td>
<td>5150</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Other specifications of a commercial hinge with position control and torque.
try and constructions standards requirements, and the product specification (Figure 19) contain more or less all the mentioned considerations, facilitating the choose process over the diversity of options.

**Bearsings**

Sliding and rolling bearings, by containing fluids to separate the surfaces of contact, are used to reduce friction between connections. Sliding bearing (Figure 21) uses only fluid, support high loads with high speed revolution and are impact-resistant, noise-absorbent and highly durable but with higher degree of maintenance. Roller bearing (Figure 20) use intermediary elements to transfer forces, requiring lower lubrication and maintenance, but they are susceptible to impact damage. They are cheaper and of more common use, and sometimes can be inserted into a case (Figure 22) that can offer protection and motion control.

Roller bearings can be also used to rotational movements (Figure 23), in larger buildings elements, to distribute the load in parallel or perpendicular axis of rotation. Common bearings are mostly used to translation movements with the basic principle of wheel-rail systems (Figure 24), where the combination of rollers distributes the load into the profile of the rail accordingly with the axis of movement (Figure 25). Interlocking profiles may be used to avoid horizontal displacement.

20. Example of roller bearing over a rail.
21. Examples of sliding bearing.
22. Roller bearing in a rail system with a external case.
23. Project of Rotatable House Cube, ball bearings are used to rotate de building in z axis.
24. Wheel-rail system, the combination of roller bearings and rails to create translation movement.
Either ways, there is a vast option on the industry market (Figure 26) and the design is being constantly mechanically improved to permit higher load bearing, better geometrical openings and lower maintenance.

3.1.3. Control Mechanisms

Control mechanisms perform connection between components that goes from putting a body in motion, to adjusting its force and speed and changing direction of movements. Control means include sliders, gears, pneumatics, actuators, hinges and linkages (Figure 28).

The basic principles of these mechanisms can be divided in four main types of simple machines (Schumacher, 2012) (Figure 29):

1- Rope and rod- allow rigid objects to be pushed or pulled using a rope and bar, applying the same amount of force in the same direction but at a different point.

2- Rope and pulley- direction of the force can be changed

3- Lever- allow to change the magnitude of the force

4- Inclined plane- change magnitude of force.

25- Load distribution on rail systems accordingly with the position relation.
26- Commercial examples of bearings.
27- Project of St. Ingbert, the combination of hinges and bearing/rail permits the folding and sliding movement necessary for transformation.
The combinations of these principles generate compound machines that aim to apply as efficient and target as possible in relation of the movements desired (Figure 30). For example, the House N°19 uses the principles of rope and winches to realize the opening (Figure 31 and 32), it’s a simple rotation movement with hinge connections, but the ropes compound permits the movement, controls the angle of opening and helps the load support of the hinges.
**Gears and transmission**

Adapt the mechanical force into output power in form of translation or rotation movement (Figure 33). Gears provide adjust of power and change direction of applied force, is possible to convert translation into rotation and vice-verse.

**Actuators**

Actuators are the mechanical elements required to put a body in motion (Figure 34). It consists of a system that converts power into mechanical work.

Electromechanical actuator produces different kinds of movements – rotation and translation- thought the arrangement and articulation of the static part (stator) and the moving parts (rotor or armature) that compose the electric motor. A local provider or energy carrier must provide the energy input to activate the operation, and in the case of portable architecture, the availability of this energy source must be considered.

Hydraulic and pneumatic actuators are fluid based and have a high power output in relation with their size. These systems, depending on the size and fluid used, need the support of a pump and a pressure accumulator or fluid reservoir that can be connected to the machines by pressure lines and placed somewhere else. Hydraulic systems operate with low-compression oils as their pressure device, stronger than air-based pneumatics systems. They actuate with close cycles, needing pressure lines, reservoir and filters units- which need to be environmental supervised because of the risk of contamination by the fluids they store.

Pneumatic actuators work with a pressure device (air) that can be liberated in the surrounds (open cycle) being less complex and more cost-effective. It’s also the most used in construction as a piston driver that after a initial power (hand-operate) realizes the motion required with control of direction and a medium load bearing capacity (pressure of 6bar and power output of 30n). Normally, at the end of the opening process, the

33. Examples of gears and it movements possibility.
34. Examples of actuators and it movements possibility.
35. Infiniti pod by Maynard architects, and the use of gears on the mechanisms.
pistons become a part of the static substructure, load supporting the component and keeping it in place (Figure 36).

3.1.4. Mechanism Chooser Chart

A chart is presented where it possible to make the relation between mechanism and motion with type, direction and force of movement.

![Mechanism Chooser Chart]

Figure 36

36. Infiniti pod by Maynard architects, uses pneumatic pistons to open and support the panel components.
3.2. Load Bearing Structure

Unlike static structures, the requirements of mobile structures differ because movements are necessary and are part of its transformations, and issues such as stiffness, stability and resistance must not be simply addressed, but controlled. Stability is essential both in its “closed” and in its “open” positions (Schumacher, 2010), but is unlikely to be achieved during transformation process and mobile buildings that don’t have an auxiliary static structure usually need support machinery during movement- for example cranes. This generates high operating costs and compromises more easily a long-term operation of mechanisms and connections.

Transformable and transportable buildings are, from a principle, reversible to enable the compactability and transportation between location and use. The incremental architecture between modules are sometimes possible and depends directly from the design proposed, and is more common when related to military and residential uses – as hospital and emergency housing.
Comparison between static and kinetic structures

<table>
<thead>
<tr>
<th>Principles</th>
<th>Static Structural Systems</th>
<th>Kinetic Structural Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>There should not have change in form with the change of forces</td>
<td>The deformability of the system allows mutation. Each element must have certain rigidity.</td>
</tr>
<tr>
<td>Stability</td>
<td>The absence of motion with respect to the medium</td>
<td>The portability of the system implies motion. Is defined as the non-presence of undesirable motion.</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>The stillness of the system through annullment of forces</td>
<td>The difference between forces generates displacement.</td>
</tr>
<tr>
<td>Resistance</td>
<td>System integrity</td>
<td>System Integrity</td>
</tr>
</tbody>
</table>

It is necessary to consider the transportation methods; it restricts the dimensions of the folded building and the overall weight. And regardless if the buildings include the chassis or hull (Figure 37) into its design and structure, or if auxiliary lifting points (Figure 38) and vehicles are needed to promote displacement, the structure has to absorb the stress generated by the movement (see transportability in chapter four). Contemplating the foundations is also an objective, it’s important to have the perfect level in the buildings for the proper occupancy and the correct function of mechanisms. The mobile architecture can be placed in different locations with different contexts, and it is important that the foundation is flexible enough to adapt without improvisations.

The building structure, indifferent if its self-erecting or has an auxiliary static structure, need to be capable to bear the load in three different moments: the close position- usually when transports also occurs and it has to be stable during lifting and displacement; the opening position- when transformation is taking place and structure is not stable; and the open position- where the transformation has been completed and components are locked in place and the stable structure is once again reached. This is important to understand, because it helps to clarify why the pod/capsules system typology is the most used when projecting and the pantographic are the more explored in research groups. The first incorporates a secondary static structure that besides been stable at all times, it serves as transport container-facilitating operation and reducing costs. The second, is not fully stable during transformation, but is self-loading and with the use of the right mechanisms doesn’t need auxiliary equipment’s to deploy.

In order to determine specific aspects of each type of structure and based on Zuk and Clark characteristic of mobile architecture, the structures are divided into four parts: Kinetic Components, Dynamically Self-erecting Structures, Deformable Architecture and Fixation and Foundation.

37- Nebula by Maynard architects, , the wheel and axes for transportation where incorporate in the structure in the beginging of the construction.
38- An example of corner lifting points in containers.
3.2.1. Kinetic Components

Kinetic components refer to the transformable buildings that have a frame structure divided into several movable parts that are independently supported by a secondary structure that remain intact during movement. While the mobile components are responsible for the transformation of the space, the static structure supports the internal load and the force generated by these movements, and usually incorporates the transport method (lifting or hull).

The typology commonly associated with this type of structure is Flat Packed and Pods/Capsules; they are used in large scale commercial projects and the reuse of shipment containers. But the combination of the container method with membranes and scissors structure is the design most frequently found, and more effective in terms of technique, expansion and use.

Static Structure

The static structure is a tridimensional frame, with load distributions on post and beans, normally in steel and with little variation in its rectangular form (Figure 39). It can be incorporate in the final building design and need to foresee the lifting point or hull positions for even load distribution during transport (Figure 40). The movable components are connected to the structure and the type and direction of movement have a direct influence in the structure that not only assumes the overall load, but also the forces as a result of movements and transformations.

To define the dimensions and characteristics of this secondary frame is necessary to determine the purpose and use of the space the structure generates (Figure 41). Is the frame only

39- Tridimensional static frame, where the principal loads are in the corners.
40- Sushi-Box, a container re-used structure with auxiliary frame to support wheels and axels.
41- static structure as an auxiliar suport
   a. frame only structural
   b. the frame store the movable elements during transportation
   c. the frame is used as utility space.
structural or it will work as a container for transportation? And if it works as a container, the interior space needs to be usable in close position or can store the movable components? It’s necessary to take account that the maximum width should be the limit of transport permits -international shipping container maximum width is 2,42m and the European road regulations are 2,55m.

In accordance with the sense of sustainable and recycling, many architects choose to reuse the shipping containers, they are cheap and have a structure ready to use, and have a trendy design appeal. But the resources to make the container habitable are extensive, expensive and with high chemical impacts (see materials chapter), plus the structure is limited and narrow. These encourages many to build a similar scaled structure, with maximum dimensions of road transportation (the 13cm permits to insulate the building) and often imitate the aesthetic aspects of a real container. Used shipping containers are used in simple transformations – mostly rotations, to minimize the adaptations and when the project incorporates a hull or has more complex transformations, a container-like structure is build taking advances on the road regulations for dimensions.

**Kinetic Components**

Kinetic Components are load bearing of at least its own weight, and in this case, of interaction with static structure frame, they are responsible for building transformations. Two main objectives can be observed in the transformations of a pod: the interaction with the exterior, where the internal space is a utility or storage of equipment, and the opening permits integration between interior and exterior (Figure 43 and 44); or it can promote the change of volume, in which case, the area of internal space is multiplied for occupancy (Figure 42 and 45). Schumacher says, in the book Move-2010, that “the openable surfaces of a building envelope relate directly through their size, direction, location and manner of opening to the function and usage of the space within”.

42- Cocobello, the open of the envelope multiply the internal area.

43- Infiniti pod, the opening of the envelope integrates the interior with the exterior.

44- Muvbox, the interior is used as storage when closed and as a kitchen when open.

45- Puma Mobile store, the area doubles as the envelope slides open.
The load distribution can be top-hung or standing system and has a directly influence by the movement (rotation or translation) and the position of connections. Standing system is when the load is transferred through the connections into the bottom of the frame. In top-hung system the element hangs from the upper part of the frame which impacts structurally on the frame and its anchorage (Move, 2010)(Figure 46). The typology of movement influences when, for example, a rotation element as a swivel or flap and the gravity exert a force perpendicular to the angle of movement. The larger the element, the greater the force applied (Figure 47). It’s where mechanisms make the difference, they are not only used to control and realize movements, but as a secondary support to these elements. For example, hydraulic and pneumatic systems are being used to realize translation motion, lock the element in position and support the weight (Figure 48). Ropes and gears systems are also being used and both systems can be hand-operated or automatic. Remembering that in an automatic and hydraulic system the weight and space needed for equipment must be considered.

3.2.2. Dynamically Self-erecting Structures

This concept includes the buildings that through the joints and connections can deploy without auxiliary structures or equipment. The mechanism to achieve this is the use of linked, folding supports in a cross-cross “X” pattern, known as a pantograph (or scissor mechanism). The upward motion is achieved by the application of pressure to the outside of the lowest set of supports, elongating the crossing pattern, and propelling the structure in the deployable direction. The direction and form of the deployed structure can be defined by the angle and position of linkage between the bars. The most difficult point is to determine how much of opening each scissor will realize, how to achieve the precision needed at the end of deployment for the

46- sub-structure for a top-hung system with a hydraulic cylinders as actuators.
47- the dimensions of elements make a difference in the mechanisms and structure as where bifold door are less stress on the building, on the door header, on the door frame and on the hinges.
a. horizontal opening with hydraulic system.
b- bifold opening with rope and gear system.
48- Cocobello, the project uses hydraulic cylinders as a lifting method to open the envelope horizontally and vertically.
structure be perfect connected and stable.

The first option is always hand-operations that with a simple mechanisms and visual work can realize the deployment from close to open position and make the necessary adjustments. To achieve this, the articulated joints can utilize hinges with control of degrees of freedom; turnbuckles which work as a tensor and control deployment amplitude (Figure 49). A common example for this application is the canopy tents, which can be deployed by two persons and put into position in minutes (Figure 50 and 51).

![Figure 49](image)

The use of automation and electronic control of openings is increasing, and with it computer programs specially developed for this purpose. The contraction of the scissor action can be hydraulic, pneumatic or mechanical (via a lead screw or rack and pinion system) and with the right control, specifications and leveling in site these applications can, not only put the structure in motion, but also control the opening of each mechanism (Figure 49). Also depending on the power system employed on the lift, it may require no power to enter “descent” mode, but rather a simple release of hydraulic or pneumatic pressure, allowing a fail-safe option of returning the structure into close position by release of a manual valve- as used in scissors-lift on construction sites.

![Figure 50](image)

![Figure 51](image)

The best use found for mobile pantograph structures is the portable stages, two projects use the scissors structure to promote deployment in site and simplify and accelerate the installation of stages. The first is Twinstage (Figure 52), that in

![Figure 52](image)

49- The opening and closing of a scissors structure.
   a- with the auxiliary of an actuator
   b- with the help of movable connections, that with the design can regulate the opening amplitude.
50- Canopy tent self-erecting structure hand operated. the connections have control of amplitude opening.
51- Canopy tent fully deployed.
52- Twinstage, in this image is possible to compare the structure design project with the final construction. In blue is the initial form volume of the truck.
eight hours can be transformed from two structures mounted in a 13m dual axle semi-trailer to a performance stage of large dimensions (24 x 13.5x12m). It uses a double single scissor structure in each side of the building and with a heavy lift hydraulic cylinder as actuator both structures are raised simultaneous. Scissors are formed by rectangular steel profiles linked at the middle by a commercial-type rotating pin and at the bottom part on the platform, their position being fixed and secured in place by fixing elements and rotation being enabled by a pin, with the opposing end being fixed onto a commercial bearings system, that moves along the guide (Patent EP 1754845 A1, 2005) (Figure 53). This stage has a European patent by Aragonesa Carpas and is produce commercially in south Spain.

The second project is a deployable stage, under development by PhD student Natalia Torres of UPC Barcelona Tech, that consists of six structural beams connected in a extremity that open horizontally, with structural link bars and unfolding floor, to form a half-circle platform (Figure 54). Each of these beams supports a scissor structure, with tarps sections in between, that once deployed forms an individual arch and a half hemispherical dome as a whole structure. Connection between bars is plan bearing type, and the project predicts a central piece as connection mechanisms at the top union of the arches, that once secure and locked will ensure the structure overall stability. Structural system is been studied in wood, to analyze if accomplish the security requirements of a cultural infrastructure against earthquakes and wind.

3.2.3. Expandable Architecture

Expandable architecture refers to an architecture transformation which fundamentally affects the whole building form and where the components parts are pre-hinged and continuous, and remains so through transformation (Zuk and Clark, 1979). This can be also the characteristics of kinetic components and self-erecting structure, but the major difference is that in expandable architecture the basic elements are connected at all times and depend of each other to achieve transformation. Be-
sides these, this architecture may be referred as “expandable” and takes advantages of the combination of rigid and deformable elements for construction. And it interacts with the previews structures as being capable of self-erection or using an auxiliary structure.

**Rigid elements**

The hardware type and the folding sequence used by expandable architecture is what define the structural possibilities and form. The mechanism connectors must be capable of being locked and structural once the transformation is finished (Figure 55).

**Flat packed**

Pre-hinged construction systems, usually with a kit form of auxiliary parts. Folding mechanism is commonly used in this system. A notable advantage is the little depth or thickness in transportation, being able to transport a larger quantity in a same vehicle. As the building is unfolded, the structure is also unfolded and within the envelope, it’s unstable and there is the need of auxiliary equipment. Once the unfolding process is completed, and the fixations and locks realized, the rigid elements have a load bearing capacity and are stable (Figure 56). The use of an auxiliary static structure is an option, but usually the dimension of this structure is limited to the load necessity and it is not used as a container for transportation.

**Deformable elements**

An important advantage to flexible materials (textiles and membranes) over rigid elements with hinges or pivots is that in the folded position they occupy less relative space and are

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55- Movable connection with locable and load bearing capacity.
56- Flexhotel, uses the premises of flat packed containers to improve quantity transportation.
extremely light and flexible in their application as surface cover. However, the structural capacity is limited and structural rigidity has to be achieved by an external influence: a separate structure, pneumatics or chemically changing the material once erected (Zuk and Clark, 1979).

Membranes Systems

Textile membranes provide structural function when stretched over a framework depending on the material specifications. An auxiliary structure of rigid materials can be within the membrane, and the combination of both in deployment is what conforms the building (Figure 57). It’s only stable once fully stretched and with the relation of structure (bars), membrane (cover) and auxiliary cables (auxiliary tension) with full tension. Textiles and membranes can be used as cover skin in preview structures (Figure 58 and 59).

Pneumatic

In a system of pneumatic structures the structural stabilization is the result of pressure differences—usually in air. When deflated, the membranes have flexible form that can be folded into very compact volume and light weighted, and can be transformed quickly into a three-dimensional object by inflating air under pressure. This way the membrane becomes a pneumatic stabilized membrane and acquires some structural rigidity, but, because of the lightweight, is unstable under wind loads and need the auxiliary of cables to hold structure in place.

Inflatable buildings are built with two layers of membrane connected together forming a chamber that, pressurized with air, produces a rigid structural element which allows large span structure to be achieved. An air-supported building requires air-
locks at all access points to prevent the air being lost when doors are opened, since the entire occupied space of the building is pressurized.

3.2.4. Piers and Foundation

The fixations and foundations of transformable and transportable buildings are probably the crucial part of a structure project. The correct leveling of the building is what can determine the correct function of connection mechanisms and mobile components. Observing the constructed buildings, it is evident how this matter is neglected by examining the adaptations made in foundations to suit the project location (Figure 61). For being transportable, a project needs to foresee the different location sites and possibilities that the building may encounter in throughout its life. For being transformable, the project needs to foresee the benefits provide by an auxiliary structure as Jack leveling.

There are multiple options when choosing piers and foundations, and all depends on the project and soil conditions of the terrain, but a few basic recommendations can be made. The piers height must be adjustable, and long enough to permit terrain variations. If no need of foundations, the base should have at least a pad to eliminate deflections. And when foundations are require, be for bad soil, large use or seismic vibrations- the use of removable pre-cast concrete and metallic pins should be considered (Figure 62).

It’s been said before that a mobile and temporary building don’t necessarily means that it is temporary in use and location. Some transformable buildings are set in terrains for a large period of times, and when used in terrains where elevation and

61- Projects invest in high technologies for operations, but low consideration on feet and foundation.
62- Pre-cast concrete that can be removable from location.
63- Projects that use the tradicional concrete blocks made in-loc.
grading are necessary, a higher quality of piers and pads should be specified. Traditional in situ concrete blocks are commonly found (Figure 63), but not recommended, once the build is moved again, it’s not possible to recover the material, and a new foundation is going to have to be set in the new location. Also, the whole principle of transportable architecture is the mobility possibilities without affecting the surroundings, for this reason detritus should not be left behind on terrain.

So, in the use of concrete, a removable prefabricate concrete blocks are suggested, and when exists the possibility of preparing the terrain, large slabs (100x14x200cm) can be considered to be an easy installation. Other option is the prefabricated pad foundation, made of pre-cast concrete parts and fixed to the ground using steel rods sunk in an angle-pin foundation (Figure 64). It works as a single foundation, and like screw foundations, provide a higher load capacity and can be easily removed and reusable (container atlas, 2010). Screw piles are a steel screw-in piling and ground anchoring system of building foundations which supports a fixed or adjustable support head plate (Figure 66).

Base pads are used as a base plate to eliminate deflection and preventing the piers and foot of sinking into the ground. The size of a pad is directly related with the item it supports,
material and variation of load capacities. In the commercial catalogue is possible to encounter pads with different materials that are light-weighed and low dimensioned, which favors the relocation and reuse (Figure 65). For piers are used plywood, metallic and ABS pads; for footing are used metallic and plastic; nevertheless, the more advertised and commercialized is the plastic and ABS bases, reassuring the lightweight properties and the capability of absorbing vibrations.

The principal differences of piers and footing are the load, the height and time of use locations- for faster relocating buildings, the footing system are easier to use (Figure 67). But booth should use the screw jacks mechanical devices to lift and leveling the buildings. The "jack" employs screw thread or hydraulic cylinder to lift heavy loads and apply great linear forces. Normally, screw jacks are simple mechanisms that need to be manually operated until reaching the grading desired, they can reach high load capacity (1.5 – 3tons) and, when threaded, high height (24 inches) (Figure 68). Although, they are not recommended for buildings that need complex grading adjustments because of the difficulties of accurately assemble and risk situations for workers. They have great use for foot of buildings and kinetic components, in this last case, they can be an auxiliary support for the frame structure and help to lock the components in place.

Mechanical jacks operate with hydraulic or pneumatic cylinders and can reach a more powerful lifting capacity (2.5-4 tons) (Figure 69). Besides the faster and easier lifting systems they can be manually operated or electrically controlled in unison with a single remote control unit (Mobile Outfitters). They offer the possibility of realizing the simultaneous lifting and leveling of individual jacks, without the need of a specialized worker, and
from a control panel (Figure 70). The most developed products offer an automatic leveling with a precision of +/- 0.1 degrees and with a safety shutdown when permissible gradient is exceeded.

3.3. Surface Elements

Surface elements address the last of the three components that sub-divide transformable buildings, representing the active layer and inquiring the specifications necessity of covering materials, sealing joints and installation systems.

The usage concept of portable architecture is a pre-defined room with low standard in terms of fitting and equipment; in certain cases it may not even be possible to enter the building, which is instead used as supporting structure. Nevertheless, the overall building must fulfill at least the requirements against rain and wind proof, having the correct sealing between movable parts to protect the interior. Other requirements, such as sound proofing and thermal insulation, need additional measures according to the demands of each project.

Shearing layers identified functions with varying life-cycles in a building and their relationship to the whole as: site, structure, skin, services, space plan, and stuff (Figure 72). Site is geographical setting; structure is the load bearing elements, foundation and skeleton; skin is the exterior surface, such as siding and windows; services are the nervous systems of a building, such as its heating plant, wiring, and plumbing; space plan includes walls, flooring, and ceilings; and stuff includes lamps, chairs, appliances, bulletin boards, and paintings (Brand, 1994). Enable simple deconstruction and re-use of elements and materials, by designing the functional levels separately, can be the directives to achieve a long-life through maintenance management.
Deconstruction can be achieved in mobile architecture through disassemble of specific parts of the buildings and their sub-parts: minimizing interference and conflict between subsystems and the parties controlling them; enabling substitution or replacement of each part during design, construction and long-term management (Kendal and Teicher, 2000). A good strategy to achieve this is to reduce the assembly parts, by using better specific materials that fulfill more performance requirements. Reducing assembly time and cost depending on methods and processes with a faster implementation and a less potential to failures (Figure 73).

3.3.1. Materials

Materials can be looked at through cover components and structural and operational components, but in this case of buildings, skin and structures overlap at many points, where the structure elements are insert in the skin or a unique element exercises the function of both layers- load-bearing and enclosure.

Structural and operational are mainly materials such as metals, which are malleable enough to allow bends that form bars with high load capacity and rigidity. Or wood in form of beams and structural composite panels. Structures that work with membranes need achieve structural rigidity in the form through the tension in the membranes; it can be through the addition of some outside influence- a separate structure, pneumatics and chemically changing the material once it is erected.

Covering materials in this type of building should not only perform properly as enclosure, but they should also resist repeated movement and environmental changes before, during and after transformation (Asefi, 2010). Also, the skin contributes to the self-weight of the construction and in the dimensions of movable elements (Schumacher, 2010) and light-weight materials should be considered at all times. Industry offers a variety of
options with different resistance and rigidity characteristics and the shape alterations of the cover components need to be think of since the beginning of the project. Is the skin stable and moves with the structure, or is it flexible and cover the structure as it moves?

In this case skin is not consider exterior cover, but also internal. And long-life of skin is considered the best way to keep the low cost of a transformable building maintenance, and for this, not only the aesthetic should be consider, but many factors of materials characteristics.

Translucency

The necessity of internal natural illumination; external elements provide security and privacy functions (Figure 74).

Fire

For facing different environmental conditions in each transformation moment or in the different location, transformable buildings are more vulnerable in comparison with static architecture. Non-combustible materials, that shrink and do not fall down when they are affected by heat, can decrease risks of fatalities in case the structure collapsed or fail to operate (Asefi, 2010).

Water-proof

The necessity of a material to be water-proof is not only about been able to keep the outdoor humid from the indoor environment. Because of transformations differences between closed and open position, many elements that once in open position are an interior finished, when in closed position are in the exterior environment suffering the action of weather (Figure 75). Considering that all material should have a water resistance is important because the interior and exterior have a tenuous or none separation and the finishes of covering materials are normally the ones that need more maintenance.

Mechanical Resistance

If the materials are being used as structure elements, the rigidity at some point will be mandatory. But been used in as a cover material it all depends on the structure and the movement expected. Light weight and stable materials (Figure 76) are good to be used

74- The use of transparent materials in the improvement of natural illumination.
75- The material selection need to take into account the interior x exterior relation where the materias need to be water resistent.
in panel frames related with rigid elements movements, normally the elements is not folded, but put in movement through movable connections – rotation, translation. Deformable elements are soft and flexible (Figure 77) and used as a skin cover of movable structures, being fold and unfold with then. The frequency of the opening and closing and the bend capacity expected of the material should be consider.

![Figure 76](image)

**Cleaning**

Self-cleaning materials prevent that dirty particles stick to the surface and are easily removed with a little rain. It helps to lower the maintenance costs and the depreciation of the building appearance. Another option is the anti-adhesive and graffiti materials in projects inserted in an urban contest.

**Insulation**

In terms of being able to be inhabited, an interior must have the minimal thermal insulation; acoustic insulation depends on the project necessity and specifications. The insulation is a challenge, because of the low dimensions of panels and structures related with portable architecture, it’s expected that the cover materials will be as efficient and low dimensional as possible.

![Figure 77](image)

Spray foam insulation, with polyurethane, is said to block all three forms of heat transfer, and, depending on the composition, and are capable of being airproof and offer some control of moisture.
and sound (Figure 78). The low dimension of the coating thickness and the quickness of its application are another benefit, but the worker has to go under full body protection because the foam before being “cured” is toxic, as well as under heat in case of fire.

Rigid insulation panels can be made of fiberglass, rock or slag wool and plastic foam (Figure 79). Normally with some structural capacity, are strong, stable and impermeable and provide also acoustic insulation. They come in various thicknesses and can be assemble mechanically to the structure, permitting further recycling. The variation is the called blankets, with have smaller thicknesses and no structural stability, but can be made of reused materials as natural fibers.

Recycling

The reuse of materials is a sensible matter; the actual standards of society expect that most materials used in construction come from a recycled source. The reality is that recycling is always complex, mostly because of the assembly methods used and treatment that elements go through to have a longer life against weather and animals. Many materials as wood, plastics and textiles can go through a process of recycling to become, for example, panel or insulation elements. But materials, or components, that have being connected or assembled by an auxiliary chemical material usually are more complex of being reused because of the complication of detachment. Chemical paints and treatments used as base for conserving the structures is also a problem, for example, in the shipment containers (Figure 80), where the based paint has chromate, phosphorous and lead and the flooring have pesticides with arsenic for long-lasting in the see environment, but making the structure itself inhabitable. The waste of machinery, time and resources to make a container habitable and the small dimensions it have, stimulates professionals to build a similarly scaled structure using wood or metal framing; it’s cheaper and consumes less energy.

Although this research doesn’t aim to analyses the chemical and physical properties of each material, assuming that the reader has basic preview knowledge, two materials, due to

79- Rigid panels insulation
a-the manufacture of a module.
b- the detail of a composite panel with rigid insulation.
80- Reused container and the adaptations made to make it habitable.
its importance and complexity will be give further information:

**Composite materials**

Composites are forming by combining materials together to form an overall structure that is better than the individual material. They can be classified by: L—reinforcing describes fibers that are strategically oriented to increase the strength of the matrix (Figure 81), and R—particle inclusion by which the matrix is changed at its base thought he manipulation of the mix (Smith, 2010). The panels created by composite materials can have a better development in structure, insulation, bending capacity among others, depending on the basic materials and the other used in the layering.

**Membrane materials**

Most fabric structures are made of actual fabric, typically coated and laminated with synthetic materials for increased strength, durability, and environmental resistance (Figure 82). The combination between the fabric type – cotton, polyester, fiberglass, with the topcoat – PVC, PTEFE, is what determines the final properties of each membranes. Being the fabric responsible for tensile, tear and adhesion strength and coating for flame retardancy, color variation, better preservation of properties and flexibility and self-cleaning properties. When choosing a fabric, it should be consider the stress versus strain -load x elongation, expected service life, the joining -like welding and gluing, the behavior around fire and shading coefficients (IFAI).

Independently of the material to be chosen, it’s not expected that an architect or designer have the full knowledge of it properties and behaviors, but be capable of defining the basic principles and necessities of each construction. It’s stronger recommended to consult with specialists and manufactures before making the final specifications, especially because every day improved materials are put in the market. Because a good project specification should consider architectural concept, technical developments, engineering design, material development and experience in manufacture (Asefi, 2010).
3.3.2. Joins and Sealants

Probably the biggest challenge in transformable architecture design is to find the proper method to fill the gap generated between connections of movable elements. To provide an environment wind and water proof when fully deployed is a tough task, because sealing and joins have to be flexible enough to not compromise movement development during closed position and transformation, and be stiff enough to, when in open position, ensure sealing and even helping in the locking of movable components.

Two main families of sealants can be identified: fluid sealants and preformed products. Fluid and gel sealants are poured into joint gaps with the help of a caulking gun in order to prevent the infiltration of water, air, insects and dust. They present a good elasticity and tear resistant, being excellent in order to fill gaps between components, but not in order to permit movement between then. They can be found as latex, silicone, polyurethane and acrylic products.

Preformed products are join sealants usually available in strips or continuous lengths in rolls. They are more common in rubber, fiber, foam and plastic materials in general (Figure 83 and 84). They don’t fill the gap, but as a flexible material, once the elements are moved into place they provide a physical barrier for the pass of water and air. Indifferent of the type of sealants, physical properties such as tear strength, elasticity, fatigue, and abrasion resistance need to be matched to the sealants intended use (Scott, 2013); and applications specific characteristics are also important features.

83- Rubber strip mechanically conected to a botton door for sealing.
84- Examples of preformed sealants.
85- Overlapping joints
86- Project where all the borders are covered with rubber, not only sealant, but help to keep the panels in place.
87- Types of joints.
Joint sealants are generally designed for specific joint types, and one of the best ways to improving the connection and seals is by increasing the contact superfcies between movable elements (Figure 85 and 87). It's really unlike to make connections between the material cover layers- unless it's a membrane cover, but rather through the frame of the elements, that in many cases contains a sealing rubber profile. The similarity of moveables elements function with doors and windows is factual, and the same strategies of sealing can be made.

A tangent problem is the interaction between movable connections and their sealing, as a way it not interferes in the movement process. In this case, flexible materials can be used externally to the connection, for example hinges, in a way that when rotation is realized the seal can stretch or be compress in a way that permanently cover the mechanisms (Figure 88 and 89). Other options are the extruded continuous hinges, that can have the width of the element an, as entire profile, perform the closing needed.

![Figure 89](image.png)

The aesthetic impact of construction components such as profiles, channels and guide rails necessary for the functionally of movable elements have to be taken into account. Technical realization and fnishes of these elements may be uneven and cause obstructions on floors and the gaps may fill with dirty which over time may cause functions problems.

### 3.3.3. Installations systems

As other components of transformable architecture, installations systems have to be flexible enough to adjust to elements movements. The basic installations systems in transportable architecture is the electrical, initially for illumination and

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88- Rubber hinge protector in different types of opening panels and doors.
89- Flexible hinge.
90- Seal strategies in top, middle and lower frame connections.
auxiliary equipment’s, that is ready to use and can be connected on site via a socket power input. Wiring usually pass inside movable panels and pass thought the connections with a hose with loose length. When the system is set into motion by power, the wiring of electrical and hydraulic mechanisms installation have to be foreseen, and also the equipment’s it need to work properly. Usually these installations are located together in an easy access place inside the building, with a unique system of control panel located on one of the buildings sides.

Water installations are more limited to use of the buildings, and in many cases, the modules are specially projected to be used as kitchen or bathrooms, or another projects that require water systems. The water facilities are concentrated in a part of the structure, normally static at all times, in order to facilitate installations and transformations (Figure 91). In case that the pipes has to go thought a movable connection, models of malleable pipes can be used. The input and output of water can be made via external connections; in with case the water systems will only be available when an exterior source is available. And have the auxiliary use of water reservoir and sewage tank, where the refilling and cleaning of tanks have to be previewed and scheduled.

Self-sufficiency in energy, water and waste management is also possible in some units that come with auxiliary solar panels, rain water collectors and sewage deposits (Figure 92). Normally these self-sufficiency is limited is time, depending on the storage capacity of each module (Figure 93) – from batteries to water supplies, and the consume preview, and have a use more targeted in medical units, military and shelter for emergencies. For commercial usages, units have plumbing and electrical systems are preinstalled and ready to plug in; when there’s a need for auxiliary self-sufficiency, a service unit can be put in place and provide the energy and water for several buildings.
4. Transformable Design Strategies

To design a transformable structure, a great understanding of geometric conditions and the connection between elements is necessary, and for that knowledge of the buildings components have already been discussed in this research. This chapter is about the design decisions prior project and their effect on the final result. Aiming that every project, from the begging of project to the end of the life-cycle, can reach: easy of execution; reuse and cost reduction; expansion, deployment or transportation; maintenance and repair; and beauty and functionality.

The criteria here used to define strategies, are based on the publication of Maziar Asefi and his work with large scale transformable structures, and have been adapted to the scale of transportable architecture and to the premises of prefabricated architecture.

These criteria derive from the function and size of the structure, design context, type of use - temporary or permanent, expected lifecycle and criteria that related to the particular project. The skill of a good designer of such buildings is to establish a balance between requirements and constrains such as available resources, financial issues, structural and operational concerns and maintenance issues (Asefi, 2010).

The whole premise of prefabrication, which hinges on the uses of factory-made components, is the speed of erection to achieve greater economy, to maintain quality, and to achieve greater economy, to maintain quality, and to decrease the amount of skilled labour on site. Issues of design, fabrication and transportation related to the need to maintain continuity of the market by controlling ranges of sizes and number of repetitive units is important (Brookes, 2009).
4.1. Design

4.1.1. Expansion and Flexibility

The ability of the structure to be used for multipurpose applications and expansion by the assembly of several individual modules.

Everything depends on how the projects are design and the foreseen possibilities it has. The flexibility comes from the space generate by the deployable structure, the material and insulation characteristics and the interior installations adaptations possibilities. Many prototypes or commercial portable structures have multiple options for use of the structure with the adecuation of it interiors – offices, kitchen, bathrooms, shelters, and hospital. Residence uses have more requisites and regulations, but in general is possible to achieve a transformable and transportable home by the assembly of more than one module.

The expansion by assembly of several modules needs to work with the connections between modules (Figure 1), if it’s hard to work with sealing joints of movable components, with different modules, position and leveling are difficult to reach and connections are easily compromised. It’s usual to use independents mobiles elements and structures as "corridors" between buildings with the use of deformable materials on frames and skin; this way is easier to make adjustments between modules.

4.1.2. Compactability and Transportability

The degree of compactness in fully folded configuration.

The ability to be applied to portable architecture.

In general, a 3d-module for transportation is has lot of empty space and are full of air, by the basic action of folding- or sliding, bending, gather- a large structure can be easily transported by truck or rail without concern for special transportation permits for oversized rigid units. To take full advantage of the potential for easy transportation, it seems important to reduce to a minimum the amount of empty space that is trapped inside the folded form, getting the product to it final location, in the right time, in the right conditions and in a cost effective manner.

Transport options need to consider the necessity of each project: the quantities of modules to be moved over time; the distance to be covered; number of destinations and pre-positions of the building; available transports modes and the relative costs; fund-
The stability of the structure before, during and after transformation. The ability of the structure to respond to changing loads.

The structural stability must be reached at all times, independent if the structure is self-erecting, uses a secondary static structure or auxiliary equipments. All movable components must be at least self-loading and the connections mechanisms must be capable of being locked and structural, as well as movable (see more information in structure sections in chapter 3). The eventual external load should be consider as use, and basic loads as wind can be combated with the use of auxiliary structures and cables.

4.1.4. Architectural Obstruction

The affect of transformation on the function of architecture.
Is the transformation required for the use of the building? It’s necessary to define if interior is a usable space at all times, if it’s a utility storage or if it may contain the movable components during transportation. The manner which an element opens, along with its size, can extend or change the ways in which the interior space can be used. The objectives of the transformation, in terms of delimitation spaces or increasing internal area, has to be take into account before defining structure and mechanisms.

4.1.5. Operating System

The complexity of operating systems and their effects on the architectural design arrangement.

The first decision to be made is how the movement is realized: is it hand-operated or powered? It can take into account the initial investment in the project, the use and destination and the availability of workers. The more automatic the structure is, higher the initial cost of the project. The more the structure needs auxiliary equipment and worker, the higher the running cost.

The consideration is that the operation system needs to be stable during transformation, have a trigger to release the safety mechanism and when using drive mechanism, a control system that can be accessed at all times.

4.2. Construction and Operations

4.2.1. Reliability and Safety

The complexity and safety of the construction process and the safety of the structure in severe environmental condition and during transformation.

The designers need to have it clear that it may only be possible to meet demanding civil engineering requirements in terms of insulation, fire protection, noise transmittal and other safety requirements to a limited degree. The legal system is not prepared to handle the regulations and taxation, and mostly likely than not, the projects won’t need to fulfill all the construction requirements.

4.2.2. Auxiliary Equipment

The equipment required for operation and stability of the structure and construction equipment.

It needs to be clear that a structure that needs auxiliary equipment for functioning means that it depends on external agents to be usable. This dependency not only has a high cost, but

4- Flex hotel, the crane used is within the truck, that transports several modules at the same time.
5- Prada Stage by OMA, the need of 4 large cranes in location to operate the transformations.
can also cost time and compromise the schedule of operation (Figure 5). Auxiliary machinery for transformation could be justified in a project, if, for example, it is more compactable for transportation (Figure 4). When need to use cranes, the size and weight of structure need to be considered, as the size and movements possible in the site location.

4.2.3. Manufacture and Shipment

The difficult of manufacture of structural and architectural components and shipment.

It can be observed two situations in the manufacture of transformable architecture: the projects that are being built ate in a improvised location, without any control of quality or prefabri-
cation standards (Figure 6 and 7). And the ones that are build commercially by companies that already work with prefabricated architecture (Figure 8 and 9). There is no need to say that an industry environmental can improve the technique, reduce waste of materials and cost and result in a better quality of final con-
struction. But there is also the need to consider if the project is to the construction of a single module or if there is the possibilities to become commercial and have a large scale production. For shipment, the dimensions need to be the sea container stand-
ards (2,42m) or the road regulations (2,55m in Europe).

<table>
<thead>
<tr>
<th></th>
<th>20° container</th>
<th>40° container</th>
<th>45° high-cube container</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>imperial</td>
<td>metric</td>
<td>imperial</td>
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<tr>
<td><strong>length</strong></td>
<td>20° 0'</td>
<td>6.096 m</td>
<td>40° 0'</td>
</tr>
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<td><strong>width</strong></td>
<td>8° 0'</td>
<td>2.438 m</td>
<td>8° 0'</td>
</tr>
<tr>
<td><strong>height</strong></td>
<td>8° 6'</td>
<td>2.591 m</td>
<td>8° 6'</td>
</tr>
<tr>
<td><strong>length</strong></td>
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<td>39° 5 45/64'</td>
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<td>2.362 m</td>
<td>7° 8 13/32'</td>
</tr>
<tr>
<td><strong>height</strong></td>
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<td>7° 9 57/64'</td>
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<tr>
<td><strong>door aperture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>length</strong></td>
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<td>2.343 m</td>
<td>7° 8 1/2'</td>
</tr>
<tr>
<td><strong>height</strong></td>
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<td>2.260 m</td>
<td>7° 5 5/4'</td>
</tr>
<tr>
<td><strong>volume</strong></td>
<td>1,189 ft³</td>
<td>33.1 m³</td>
<td>2,385 ft³</td>
</tr>
<tr>
<td><strong>maximum gross mass</strong></td>
<td>66,139 lb</td>
<td>30,400 kg</td>
<td>66,139 lb</td>
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<tr>
<td><strong>empty weight</strong></td>
<td>4,860 lb</td>
<td>2,200 kg</td>
<td>8,380 lb</td>
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<tr>
<td><strong>net load</strong></td>
<td>61,289 lb</td>
<td>28,200 kg</td>
<td>57,759 lb</td>
</tr>
</tbody>
</table>

6- sushiBOX, construction in an improved outside location.
7- Raumbaldor, the construction took place in a atelier fot metallic profiles.
8- Morphouse, the construction line in a prefabricated industrie.
9-Morphouse, the construction line in a prefabricated industrie.
10- Standarts sizes for containers.

4.3. Maintenance and Costs

There is a need of the designer to provide comprehensive specifications that have to be considering both during the design process and in the subsequence operation and perfor-
4.3.1. Life-Expectancy

The expected life-time of the structure

Normally, there are a rapid depreciation in the mobile buildings, mostly due to the negligence of maintenance and conservation over time. The durability of the structure depends primarily on the weather resistance of the individual components and the connections technology used between them (Move, 2010). There are projects that are expected to outlive five years, and projects, that with the maintenance and substitution of elements, claims to outlive twenty years.

4.3.2. Maintenance Management Strategies

The complexity of the maintenance issues and the strategies for replacement of the components and responsive maintenance in unexpected conditions.

The more complex the system is, the more sophisticated the maintenance and management system is required, and simple solutions, sometimes can help a project to have a larger life-expectancy. It’s possible to preview the substitution and disassembly of elements parts, by using standard and modular materials and mechanisms and prefabrication premises. Regular revision on basic issues such as mechanisms, sealing and structure should be made to observe correct functioning and cleaning; at least every time the building is transformed and transported to a new location. Some military and shelter projects are sold with maintenance kit that has a few tools and materials to make small repairs in the building.

4.3.3. Capital Cost

Cost of design, site preparation, manufacture and construction.

The cost is a very relative, and depends on the situation and location of project, construction and final destinations. But a few considerations can be made: a used container is for sure cheaper than a new one (about 1/3 of the value), but the cost of conversion work is very expensive. The delivery is a significant contributor to cost, that why the attempt to exploit folding as a means to create an object that can be shipped with no waste of space. The cost of work depends on the degree and type of work to be done and the nation and region it has to be done, an social
inquire need to be developed.

4.3.4. Running and Maintenance Costs

Costs of cleaning and regular maintenance and responsive maintenance.

A project needs to preview the future cost in transportation, foundations and connections utilities to be used during its lifetime. And the use of auxiliary equipment, such as cranes and trucks, and their available time and costs. The ideal is that, even if the projected need a crane to be erected, it doesn’t depend on it to work after.
5. Final Analysis

Transformable architecture is a large field of studies, referring to different systems typologies and constructions forms. But even with this variety is possible to establish connections between each system and their components, in order to define premises and basic requirements to be achieved by architects while designing. Been popular in the 50’s and 60’s, transportable buildings never stopped to be produce, they diminish and stayed in the side of highlights.

It’s important to maintain a certain standards when defining terms and nomenclature used to describe project and research. The use of a common terminology befits the professionals in general in the moment of investigation and planning of a new design specifications, facilitating the access and sharing of information. Words as portable, mobile, manufacture can still be seeing with objection by public, and the professionals that work in this area need to assure good quality architecture, as a long-term plan, in their projects. The real breakthrough will only be significant as portable architecture when the products are perceived to be of high quality and of attractive design. Prefabrications and manufacture may be the key to reach this quality, and need to be further explored. The transformation objective is not only of expanding the buildings, but to consider the architectural parameters of a efficient and enjoyable space.

In terms of buildings components, is important to highlight that the relation between materials, structure and mechanisms connections is not just fundamental, but that the alteration of any of them, without updating the others, generates malfunctions of hardware and the system collapse. In other to do that the designers responsible for these projects should have an open dialogue with other professionals, as engineers, manufactures, constructors, in order to define the best solution and specifications for each building.

The connections mechanisms should be resistant, permit the movement required with little or none maintenance and in a reliable way. Preferably, even if an automatic system is available, the build should be able to be transformed using only the human strength. The use of electrical and hydraulic mechanisms are a good choice for security reasons during transformation and leveling, they also provide an fast and easy option for the necessity
to close the build in case of an emergency.

The structure need to be reliable at all times, be through the static auxiliary frame, the operation equipment or to the final locked position of panels. External forces, as wind, should be take into consideration when projecting; the extreme weather conditions, as snow load and thermal resistance, should be consider depending on the project objectives, use and destination. All moments of load distribution in the structure should be foreseen: as the forces generate by the movements of elements; the auxiliary support for panels; footing and foundations. Transportation methods have to be incorporate in the final structure, as a wheel system or lifting points, and the loads be even distributed to prevent deflections and damages in the elements.

Lightweight and efficient materials need to be consider in order to minimizing layering in skin elements, lower the self-weight of the build, be resistant and thermal effective, and enable temporary assemble -that permits the maintenance and larger life-expectance of the construction. The seal between movable elements and connections is essential to maintain the water and wind proof of the interior, needing to be flexible enough to don’t compromise the mechanical functionality of elements. Flexible materials as plastics neoprene can adapt to the joint form and maintain the elasticity and integrity properties for longer periods. Properties as thermal insulation, fireproof, water resistance, folding resistance also need to be considered.

Installation systems need to flexible to pass through the panels and connections, or be projected as a central distribution, inside the static structure. There is no need to have multiples access points inside the building when the project contemplates a good distribution solution. The control facilities have to be access at all times, in general being located in the sides of the build, with easy access in open and closed position. The possibilities is to have a ready to plug in system, where water and electrical power can be provide by an external source through connections, or a self-sufficient unit, that can have water storages and solar power and supply for a determined time. When working with multiple units or longer supply time is needed and viable options are the special modules with supplies, which can store larger amounts of water and sewage and batteries power.

In terms of design strategies, it’s important to define the projects transformations and transportations objectives prior project, so the design can be developed as whole and operations and maintenance strategies can be foreseen.

Design determinations include the possibility of the modules to expand with the assembly of other modules, and the flexibility of the module itself – is it possible to change configurations or materials depending on use or location? Which type of materi-
als and transformations is expected, what kind of movements the structure is going to realize. In general transformations are essential for the occupancy of the buildings, but how the architectural choices affect the internal space? How is the movement operated? Is a hand-operated system or an electrical power, does it have the security option to work even when power is not available? Are auxiliary equipment need to operate and what are they impact in the cost of construction and operation? What is the life-expectancy of the construction and the strategies for it maintenance and later disposal?

To be able to foreseen the project as whole along all it life cycle is the objective, and the prefabrications techniques may be part of the solutions. Most of projects being built now days are done in precarious and improvised locations, without any technique or quality control. Some of the modules, that are commercially available, are constructed by industries that already work with prefabricated architecture, and the transformable buildings come as an experiment for transport solutions. Transportability is probably the most important aspect of transformable buildings, which take full advantage of transportation and reduce to a minimum the empty space inside the folded form.

When you think of a shipping container as more than a box, but part of a system, the logical conclusion is that prefabricate architecture is like any other product, it can be built anywhere. And if cost of transport can be reduced by the reduction of the package, the role of transportable and transformable in architecture can be the developing of a global construction industry – that has already being explored in companies in Australia, China, USA, Canada that are exporting their construction system worldwide. These constructions may not have the final finishes as a tridimensional module, but with the improvement of techniques and standards, the final product can get to site location and require less workers and time in assembly than the typical prefabrication systems. And this is a subject that is worth being further explored.

To finalize, the conclusion is that a transportable and transformable buildings being projected and constructed right now are a good architecture when it plays the role without trying to be something else. It’s fast temporary architecture, which may provide the service as the static constructions does, because the portability and the ability to hire complete buildings means that clients do not have to find the full capital value of the buildings and they keep their options open for change.

An indeterminate architecture is created, although between limits that besides allowing change provide characteristics related with occurrences and performances that the user can control. The buildings that can modify in a significant manner their
form along a limited period of time establish a sense of identity different from the totally static buildings, and in this sense, people respond in a very different way before a mobile environment in comparison with a static. This is because the implication of the user with the building is transformed into an interaction instead of building a simple reaction (Kronenburg, 2011).
6. Future Research

Transformable and transportable architecture is a large field of actuation, and each of the subjects cover in this research can be explored into a deeper level.

The mechanical and movable connections properties and the relation with the frame structure and the movement realized can be studied. The interaction of forces, loads and movements and the impact they generate. The types and uses of mechanisms and further the products that are already available commercially.

The interaction between transformable structures and static existent constructions, as a complement, an improvement or a temporal addition to these buildings.

The most promising and of greater personal interest: the relation between prefabrication and transformable buildings for transportation alternative in the manufacture and shipment of constructions.
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www.miihome.com.au

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http://adaptablefutures.com/our-work/toolkit/

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https://www.google.es/patents/

Dynamic Global Adeems.
http://adeemsusa.com/

International transport forum
http://www.internationaltransportforum.org
7. Appendix

7.1. Project Applications

Based on what have been studied in this thesis, a few projects are going to be analyzed and described following the buildings components descriptions and the design strategies.
**Project Basic Information**

<table>
<thead>
<tr>
<th>System</th>
<th>Pod or Capsules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Kinetic components + secondary frame</td>
</tr>
<tr>
<td>Architect</td>
<td>Maynard Architects</td>
</tr>
<tr>
<td>Company</td>
<td>Arts Acess Victoria</td>
</tr>
<tr>
<td>Year</td>
<td>2012</td>
</tr>
<tr>
<td>Location</td>
<td>Melbourne, Australia</td>
</tr>
<tr>
<td>Use</td>
<td>Cultural</td>
</tr>
</tbody>
</table>

**Transformable Buildings Components**

**Movement Mechanisms**
Rotation of movable elements connected with hinges, powered and movement control by gears and ropes.

**Load Bearing Structure**
Kinetic Components with static secondary frame
Hand-operate jack leveling. Powered opening.

**Planar Surface Components**
Uses aluminum in the structure and skin, membrane in side wings covers.
The frame of the structure is sealed with rubber, not the frame of elements.
Electrical power ready to plug-in with a solar panel and battery for 4 hours.

**Transformable Design Strategies**

**Design**

<table>
<thead>
<tr>
<th>Expansion and Flexibility</th>
<th>The expansion is not prewired, but the flexibility is possible through the opening of side wings, which generates an stage area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compactability and Transportability</td>
<td>Initial dimensions: 279x280x509cm Gross Floor Area: 14.8m² – closed, 62.4m² – open The secondary frame absorbs an axle/wheel transport that works as a compact caravan.</td>
</tr>
<tr>
<td>Structural Stability and Deformability</td>
<td>Stable during transformation. No information about loads.</td>
</tr>
<tr>
<td>Architectural Obstruction</td>
<td>Interior space for storage during transportation or when in a closed position. Side wings can have the membranes open and close changing the relation with exterior.</td>
</tr>
<tr>
<td>Operating System</td>
<td>Outside electric power needed for deployment automation. Solar panel and battery for 4 hours.</td>
</tr>
</tbody>
</table>

**Construction and Operations**

<table>
<thead>
<tr>
<th>Reliability and Safety</th>
<th>No information about safety measures, only that the buildings has accessibility.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Equipment</td>
<td>Needs to be connected in a car for transportation.</td>
</tr>
<tr>
<td>Manufacture and Shipment</td>
<td>Build in a atelier of metallic profiles, responsible for the construction of the structure.</td>
</tr>
</tbody>
</table>

**Maintenance and Costs**

<table>
<thead>
<tr>
<th>Life-Expectancy</th>
<th>Highly efficient structure built for a long adaptable life.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Management Strategies</td>
<td>The structure and materials are panelised and easily replaceable.</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>No information.</td>
</tr>
<tr>
<td>Running and Maintenance Costs</td>
<td>Expected to be low.</td>
</tr>
</tbody>
</table>

1- Deployment process
2- The project shows the expectation between closed and open position.
3- The variation of the opening wings generates different relations with the exterior.
4- construction.
5- Internal view.
6- external view during deployment.
7- detail of elements frames and support during deployment.
8- view of connection between movable panel, static structure and membrane cover.
9- system of ropes and gears put the panel in movement, control and support.
10- deployment view.
# 002 _ Infiniti Pod

## Project Basic Information

<table>
<thead>
<tr>
<th>System</th>
<th>Pod and Capsules</th>
</tr>
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<tbody>
<tr>
<td>Structure</td>
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<td>Maynard Architects</td>
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<tr>
<td>Company</td>
<td>Infiniti Automobiles</td>
</tr>
<tr>
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<tr>
<td>Location</td>
<td>Australia</td>
</tr>
<tr>
<td>Use</td>
<td>Comercial</td>
</tr>
</tbody>
</table>

## Transformable Buildings Components

### Movement Mechanisms
Horizontal and vertical rotations, with hinges and pivots. Control of opening and movement, and auxiliar support with hydraulic cylinders.

### Load Bearing Structure
- Kinetic components with static secondary frame
- Screw jack footing

### Planar Surface Components
- External skin in alubond, internal in wood composite, with high resistance.
- The frame of the structure is seal with rubber, not the frame of elements.
- Electrical power ready to plug-in.

## Transformable Design Strategies

### Design
- Expansion and Flexibility: Not previewed
- Compactability and Transportability: Single module with lifting points at low part of frame. Dimensions not available.
- Structural Stability and Deformability: Stable during transformation. No information about loads.
- Architectural Obstruction: The internal space works as a storage utility when closed and as a commercial venue when opened.
- Operating System: Hand-operated with the use of hydraulic cylinders

### Construction and Operations
- Reliability and Safety: No information
- Auxiliary Equipment: Only for transportation
- Manufacture and Shipment: No information

### Maintenance and Costs
- Life-Expectancy: No information
- Maintenance Management Strategies: No information
- Capital Cost: No information
- Running and Maintenance Costs: No information

1- deployment process
2- view of the open position with vertical and horizontal rotation elements.
3- hydraulic cylinders control the openings.
4- internal view of movable elements in closed position
## Project Basic Information

<table>
<thead>
<tr>
<th>System</th>
<th>Pod and Capsules</th>
</tr>
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<tr>
<td>Year</td>
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<tr>
<td>Location</td>
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<tr>
<td>Use</td>
<td>Atelier / Comercial</td>
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</table>

## Transformable Buildings Components

### Movement Mechanisms
- Sliding with hydraulic lifts
- Control Means electronically pneumatically controlled
- Deployment : 1 hour

### Load Bearing Structure
- Kinetic components with static secondary frame. The skin structure slides for a triple unfolding.
- Screw jack footing and high load lift hydraulic jacks.

## Planar Surface Components
- Steel frame construction covered with metal and Lexan facades
- Completed sealed
- Electrical power ready to plug-in. Possibility to have water system.

## Transformable Design Strategies

### Design
- Flexibility in terms of color and finishes combinations and uses possibilities
- Dimensions: 5,48x5,55x5,16m-open ; 5,48x3,00x3,07m- closed.
- Gross area: 35.2 m²
- Weight: 13.5t
- Transported in a lower truck.

### Compactability and Transportability
- Structural Stability and Deformability
  - Stable during transformation.
  - No information about loads.
- Architectural Obstruction
  - It can only be occupied when fully deployed.
- Operating System
  - high lift hydraulic jacks

## Construction and Operations

### Reliability and Safety
- No information

### Auxiliary Equipment
- only for transportation, can be lowered by truck by itself

### Manufacture and Shipment
- Commercially available, but no information about manufacture. Can be shipped overseas.

## Maintenance and Costs

### Life-Expectancy
- Up to five years

### Maintenance Management Strategies
- not informed

### Capital Cost
- In 2003 started at 75.000 euro.

### Running and Maintenance Costs
- not informed

---

1-deployment process
2- side section of build fully opened
3- plan of the second floor fully opened
4- deployment process from transportation method.
5- the modules can lower themselves from the trucks
6- interior view
7- side perspective
8- side perspective
9- interior perspective, is possible to see the hydraulic lifts
10- close up of the hydraulic system.
# 004_ Morphouse

## Project Basic Information

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<thead>
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<th>System</th>
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<tbody>
<tr>
<td>Structure</td>
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## Transformable Buildings Components

### Movement Mechanisms

Power unit deployed in five minutes, basically rotation and translation with an electric power opening.

### Load Bearing Structure

Deformable structures, with static structure and expandable panels, metalick screw jacks.

### Planar Surface Components

The walls, floors and ceilings of the Morphouse™ are made from new technology MiiPanels™ to create a high performance space for living and working that is incredibly strong, yet lightweight. Joinery unit comes with solar panels, a wind turbine and an impeller turbine, all connected to a battery bank that can run for 72 hours without input. A 2,000-litre water tank can also be integrated into the unit, as well an in-built extraction assist sewage pump.

## Transformable Design Strategies

### Design

- **Expansion and Flexibility**: can be combined, there is the option of variation of uses and interiors.
- **Compactability and Transportability**: 90m² flat packed house totally contained within its own structural enclosure equivalent to a 40’ HiCube shipping container and can readily be transported to remote sites by sea, road, rail or air.
- **Structural Stability and Deformability**: Stable at all times
- **Architectural Obstruction**: the interior is used for storage of movable components
- **Operating System**: automatic or with auxiliary equipments

### Construction and Operations

- **Reliability and Safety**: Fully self-contained, structurally superior, energy efficient, cyclone coded dwelling.
- **Auxiliary Equipment**: Transportation, and for long-term use a mini-crane for deployment.
- **Manufacture and Shipment**: industrial constructions under prefabrication premises

### Maintenance and Costs

- **Life-Expectancy**: A MiiHome structure can stay in place for 1 month or 50 years, as short-term accommodation or as a permanent structure.
- **Maintenance Management Strategies**: not informed
- **Capital Cost**: not informed
3- structural automatization
4- unit for extra services
5- water installations distribution
6- autosufiency unit
7- Manufacture industry
8- deployment of a long-term used resi-
dency
9- manufacture industry
10- manufacture industry
# 005 _ Twinstage

## Project Basic Information

<table>
<thead>
<tr>
<th>System</th>
<th>Pantograph hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Dynamically self-erecting</td>
</tr>
<tr>
<td>Architect</td>
<td>not informed</td>
</tr>
<tr>
<td>Company</td>
<td>Aragonesa Carpas</td>
</tr>
<tr>
<td>Year</td>
<td>Patent 2006</td>
</tr>
<tr>
<td>Location</td>
<td>Spain and Europe</td>
</tr>
<tr>
<td>Use</td>
<td>Stage</td>
</tr>
</tbody>
</table>

## Transformable Buildings Components

### Movement Mechanisms

Deployment in 8 hours with 6 persons
Scissors are formed by rectangular steel profiles linked at the middle by a commercial-type rotating pin and at the bottom part on the platform, their position being fixed and secured in place by fixing elements and rotation being enabled by a pin, with the opposing end being fixed onto a commercial bearings system, that moves along the guide.

### Load Bearing Structure

It uses a double single scissor structure in each side of the building and with a heavy lift hydraulic cylinder as actuator both structures are raised simultaneously.

### Planar Surface Components

Metallic structure with PVC membrane as cover.

## Transformable Design Strategies

### Design

**Expansion and Flexibility**
Laterlas with 12m each.

**Compactability and Transportability**
Two structures mounted in a two 13m dual axle semi-trailer to a performance stage of large dimensions (24 x 13,5 x 12m).

**Structural Stability and Deformability**
Stable.

**Architectural Obstruction**

**Operating System**
Hydraulic power operation.

## Construction and Operations

**Reliability and Safety**
A structure capable of supporting 12 tons in weight and 24 kg/m² snow.
Wind resistance with side flaps: 100 km / h.

**Auxiliary Equipment**
No auxiliary equipments.

**Manufacture and Shipment**
Aragones carpas.

## Maintenance and Costs

**Life-Expectancy**
Not informed.

**Maintenance Management Strategies**
Not informed.

**Capital Cost**
Not informed.

**Running and Maintenance Costs**
Not informed.
2- one of the trucks gets in the location with the structure.
3- structure fully deployed and working
4- side view of structure, where is possible to see the scissor structure and hydraulic cylinders.
5- patent of transportations.
# 006 _EDV-01

## Project Basic Information

<table>
<thead>
<tr>
<th>System</th>
<th>Pods and Capsules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Kinetic Components+ Secondary frame</td>
</tr>
<tr>
<td>Architect</td>
<td>Yasutaka Yoshimura</td>
</tr>
<tr>
<td>Company</td>
<td>Diawa Lease</td>
</tr>
<tr>
<td>Year</td>
<td>2011</td>
</tr>
<tr>
<td>Location</td>
<td>Japan</td>
</tr>
<tr>
<td>Use</td>
<td>Shelter and Laboratorys</td>
</tr>
</tbody>
</table>

## Transformable Buildings Components

### Movement Mechanisms

Sliding mechanisms, automatic lift system and auto leveling.
Deployable in 260 seconds

### Load Bearing Structure

Kinetic Components with static structure, the envelope slides upway to double the internal area. The retractable double-shell design means twice as much space inside the unit.
Automatic lifting and leveling

### Planar Surface Components

Its completely autonomous for at least one month: the electricity produced by solar panels on the roof, the gas (hydrogen) through a system of electrolysis, water is condensed from the air (the production is about 20 liters per day), the toilet does not require water and connectivity is provided via a satellite link.

## Transformable Design Strategies

### Design

<table>
<thead>
<tr>
<th>Expansion and Flexibility</th>
<th>in form of a camp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compactability and Transportability</td>
<td></td>
</tr>
<tr>
<td>first floor: 605×259×243cm</td>
<td></td>
</tr>
<tr>
<td>second floor: 605×451×243cm</td>
<td></td>
</tr>
<tr>
<td>Total floor area: 21.14sq.m</td>
<td></td>
</tr>
<tr>
<td>Max. height: 4.591mm</td>
<td></td>
</tr>
<tr>
<td>Structure: Steel</td>
<td></td>
</tr>
<tr>
<td>Architectural Obstruction</td>
<td></td>
</tr>
<tr>
<td>the first floor is the storage for the equipments, the second floor is used as a door or office</td>
<td></td>
</tr>
<tr>
<td>Operating System</td>
<td></td>
</tr>
<tr>
<td>autonomous for a month</td>
<td></td>
</tr>
</tbody>
</table>

## Construction and Operations

<table>
<thead>
<tr>
<th>Reliability and Safety</th>
<th>Not informed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Equipment</td>
<td>Only for transportation</td>
</tr>
<tr>
<td>Manufacture and Shipment</td>
<td></td>
</tr>
<tr>
<td>Commercially available, but no informations about manufacture. Can be shiped over seas.</td>
<td></td>
</tr>
</tbody>
</table>

## Maintenance and Costs

<table>
<thead>
<tr>
<th>Life-Expectancy</th>
<th>Not informed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Management Strategies</td>
<td>Not informed</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>In 2011 started at 50,000 dollars</td>
</tr>
<tr>
<td>Running and Maintenance Costs</td>
<td>Not informed</td>
</tr>
</tbody>
</table>

1- Unit in closed position.
2- Unit in open position.
3- Close-up of the facade where is possible to see the alubond perforated skin in order to filter the light and the solar panels.
4- A fully deployed perspective with specifications
5- floor plans, the first floor concentrates the equipments, the second the room to be occupied.
6- interior perspective of a the second floor as a dormitory.
7- transportation possibilities.
8- fully open position.
# 007_ Muvbox

## Project Basic Information

<table>
<thead>
<tr>
<th>System</th>
<th>Pods and Capsules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Kinetic Components+ Secondary frame</td>
</tr>
<tr>
<td>Architect</td>
<td>Daniel Noiseux</td>
</tr>
<tr>
<td>Company</td>
<td>Sid Lee</td>
</tr>
<tr>
<td>Year</td>
<td>Prototype conception: 2008-2009</td>
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<tr>
<td>Location</td>
<td>Canada and europe</td>
</tr>
<tr>
<td>Use</td>
<td>Fast Food</td>
</tr>
</tbody>
</table>

## Transformable Buildings Components

### Movement Mechanisms
- Deployment: 90 seconds
- Complete installation: 10 minutes, 3-4 employees in service

### Load Bearing Structure
- Kinetic Components with static structure
- Some metallic footing, but mostly the leveling is improvised with wood plates

### Planar Surface Components
- The shipping container is reused and the floor is made from recycled tires.
- Solar panels on the roof generate 40% of the restaurant's energy needs, and most likely the remaining 60% comes from propane to fuel the kitchen appliances

## Transformable Design Strategies

### Design
- Expansion and Flexibility
  - Not previewed
- Compactability and Transportability
  - Dimensions Closed: 2.4m x 6.1m x 2.6m
  - Open: 4.57m x 6.1m x 2.6m
- Structural Stability and Deformability
  - Stable at all times
- Architectural Obstruction
  - The interior stores the equipment and when fully open works as a kitchen
- Operating System
  - Water and electrical system available, with option of autogeneration or plug-in systems

### Construction and Operations
- Reliability and Safety
  - Not informed
- Auxiliary Equipment
  - For transportation only
- Manufacture and Shipment
  - Standard 20-foot and 10-foot shipping container - easy to ship by land or sea.
  - A basic MUVBOX unit takes approximately six weeks of production. Depending on quantity ordered and custom finishing, the MUVBOX can take up to an additional six weeks of manufacturing time. Delivery is dependent on method of transportation and location. International shipping from the port of Montreal to Asia or Europe typically take an average of 15 days at sea.

### Maintenance and Costs
- Life-Expectancy
  - Not informed
- Maintenance Management Strategies
  - Not informed, but the Muvbox company manages the production and the restaurants. So probably have a plan of maintenance.
- Capital Cost
  - Base unit $150,000; original Muvbox $225,000
- Running and Maintenance Costs
  - Not informed

1- deployment process
2- 10 foot shipment container
3- internal view of storage when closed.
4- a module being deployed by employees
5- an open module working, foot are used for leveling the movable element, in this case working as a floor platform.
6- transportation
7- a module being equipped with the restaurants utilities.
## Project Basic Information

<table>
<thead>
<tr>
<th>System</th>
<th>Pods and Capsules and Pneumatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Static structure + expandable</td>
</tr>
<tr>
<td>Architect</td>
<td>RAUMLABOR</td>
</tr>
<tr>
<td>Company</td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>Since 2006</td>
</tr>
<tr>
<td>Location</td>
<td>Germany and Europe</td>
</tr>
<tr>
<td>Neighbors</td>
<td></td>
</tr>
<tr>
<td>Use</td>
<td>Temporary collective use</td>
</tr>
</tbody>
</table>

## Transformable Buildings Components

### Movement Mechanisms

Deployment about 3 hours and with 2-3 people  
A fan located under the grating inflates the bubble and continually provides it with air. The box simultaneously functions as a pressure gage and relief vent.

### Load Bearing Structure

Static structure with deformable structures  
The bubble nestles itself into whatever is already there

### Planar Surface Components

- Box: encased in anodised sheet steel  
- Bubble: made of translucent, reinforced PE laminate  
- Joinery: Ready to plug in water and electric supply

## Transformable Design Strategies

### Design

<table>
<thead>
<tr>
<th>Expansion and Flexibility</th>
<th>Not previewed</th>
</tr>
</thead>
</table>
| Compactability and Transportability | Box: 3x3.1x2 metres  
Bubble: 20x6x12 metres |
| Structural Stability and Deformability | the box is stable at all times, the bubble depends on the wind and rain loads |
| Architectural Obstruction | only works when fully deployed |
| Operating System | hand operated and powered air supplied |

### Construction and Operations

<table>
<thead>
<tr>
<th>Reliability and Safety</th>
<th>Weather: Exception: excessive Wind (from wind force 4). a heating is possible. Escape routes, fire safety In the bladder there is an emergency exit. The bubble is in accordance with DIN 4102 Part 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Equipment</td>
<td>for transportation</td>
</tr>
<tr>
<td>Manufacture and Shipment</td>
<td>Not informed</td>
</tr>
</tbody>
</table>

## Maintenance and Costs

<table>
<thead>
<tr>
<th>Life-Expectancy</th>
<th>Not informed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Management Strategies</td>
<td>Not informed</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>Not informed</td>
</tr>
<tr>
<td>Running and Maintenance Costs</td>
<td>Not informed</td>
</tr>
</tbody>
</table>

1- deployment process.
2- layout possibilities
3- located under a bridge. the pneumatic membrane adaptes the form to it surrounding.
4- internal view as a danceroom layout
5- located in an open park
6- view of the entering the ventilator for the air pressure are kept under the ramp.